PB80-205842

Choosing Offshore Pipeline Routes. Problems and Solution

New England River Basins Commission
Boston, Massachusetts

Prepared for
Industrial Environmental Research Laboratory
Cincinnati, Ohio

May 1980

U.S. Department of Commerce
National Technical Information Service
NTIS

United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/7-80-114
May 1980

PB80-205842

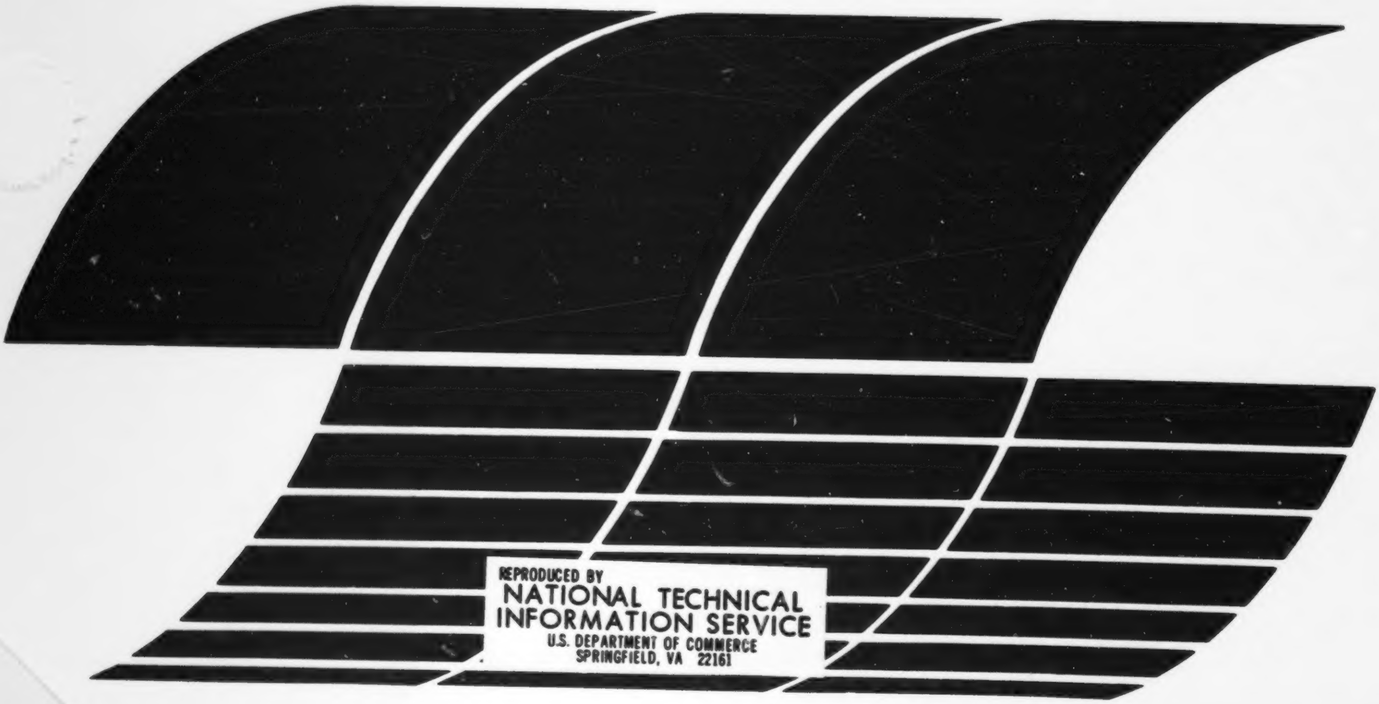
Research and Development

EPA

Choosing Offshore Pipeline Routes

Problems and Solutions

Interagency Energy/Environment R&D Program Report



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TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/7-80-114

2.

3. RECIPIENT'S ACCESSION NO.
PB 80 205842

4. TITLE AND SUBTITLE
CHOOSING OFFSHORE PIPELINE ROUTES: PROBLEMS AND SOLUTIONS

5. REPORT DATE
May 1980

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Ann M. Gowen, M.J. Goetz & I.M. Waitsman

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Coastal Programs Division
New England River Basins Commission
53 State Street, 1st floor
Boston, MA 02109

10. PROGRAM ELEMENT NO.
INE 826

11. CONTRACT/GRANT NO.
IAG No. 78-D-X0063

12. SPONSORING AGENCY NAME AND ADDRESS
Industrial Environmental Research Lab. - Cinn, OH
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

13. TYPE OF REPORT AND PERIOD COVERED
Final

14. SPONSORING AGENCY CODE
EPA/600/12

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The report discusses the environmental and fisheries problems associated with offshore pipelines. The report focuses on how these problems can be addressed during the pipeline planning and route selection process.

Geologic hazards are highlighted as the major factors related to pipeline failure which can be addressed through the pipeline routing process. Habitats and ecosystems are particularly susceptible to installation-related disturbances. These areas as well as those where geologic hazards are most likely to be encountered are described.

Fishing problems highlighted include loss of access to fishing areas due to pipelines both from platform to shore and between platforms. The effects of obstructions on bottom fishing gear are also considered. The concept of pipeline trenching for safety and stability is discussed.

Finally, criteria to use in analyzing a proposed pipeline route are presented. Topics discussed include general industry siting criteria, geologic and environmental areas to avoid in pipeline siting and methods for minimizing unavoidable impacts.

The report is designed to be used by scientists or engineers involved in offshore petroleum pipeline planning.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pipelines Oils Natural Gas Continental Shelves	Route Selection Criteria Trenching & burial Fishing Industry Conflicts Environmental Sensitivity Geological Sensitivity	13-K

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

U.S. GOVERNMENT PRINTING OFFICE: 1980-657-146/5690

EPA-600/7-80-114
May 1980

CHOOSING OFFSHORE PIPELINE ROUTES: PROBLEMS AND SOLUTIONS

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report provides concise information on the environmental impacts associated with outer continental shelf pipelines. Topics discussed include general industry siting criteria, geologic and environmental areas to avoid in pipeline siting, and methods for minimizing unavoidable impacts. This information will be of interest to all those concerned with offshore petroleum pipeline planning, including pipeline corridors and pipeline landfalls. Further information may be obtained through the Resource Extraction and Handling Division, Oil and Hazardous Materials Spills Branch, Edison, New Jersey.

David G. Stephan
Director

Industrial Environmental Research Laboratory
Cincinnati

PREFACE

In 1977, the New England/New York Coastal Zone Task Force, a group affiliated with the New England River Basins Commission (NERBC), and made up of state coastal zone program managers, recommended that the U.S. Environmental Protection Agency (EPA) initiate a research project on the environmental impacts of oil and gas pipeline construction and operation. The Task Force felt that should oil and/or gas be found on the region's outer continental shelf (OCS), they would need this type of information to make sound decisions regarding OCS pipeline routing. EPA, recognizing NERBC's continuing interest in OCS-related activities, responded with a formal request that NERBC undertake this project entitled "OCS Pipeline Construction and Operation - Potential Environmental Problems and Recommendations for Mitigation of Impacts." Work was begun in January 1978.

The first report in this series, "The Environmental Effects of OCS Pipelines - Initial Findings," was finished in June 1978, with two additional chapters added in September 1978. This second report, "Choosing Offshore Pipeline Routes: Problems and Solutions," incorporates comments on the first draft and additional information on the potential problems associated with offshore pipeline routing. Both reports were prepared by the staff of the New England River Basins Commission under the sponsorship of the Industrial Environmental Research Laboratory-Cincinnati, U.S. Environmental Protection Agency.

ABSTRACT

This project was undertaken to provide detailed information on the environmental impacts associated with outer continental shelf (OCS) pipelines. It is designed to be used by scientists or engineers involved in offshore petroleum pipeline planning, including pipeline corridors and pipeline landfalls. The information for the project comes primarily from written sources.

The report discusses the environmental and fisheries problems associated with offshore pipelines. There are two major environmental concerns: leaks or spills of hydrocarbons from pipelines into ocean waters; and potential damage to sensitive environmental areas on and near the pipeline route. Fisheries concerns center on potential losses of fishing area or gear due to offshore pipelines, resulting in loss of fishing time, catch and revenue. The report focuses on how these problems can be addressed during the pipeline planning and route selection process.

Geologic hazards (such as sediment conditions, liquefaction, scour, sand waves, erosion and seismic characteristics) are highlighted as the major factors related to pipeline failure which can be addressed through the pipeline routing process. Habitats and ecosystems (such as spawning grounds and salt marshes) which are particularly susceptible to installation-related disturbances (which include organism losses, turbidity effects, habitat alterations and changes in physical and chemical characteristics along the routes) are discussed. These areas as well as those where geologic hazards are most likely to be encountered are described.

Fishing problems highlighted include loss of access to fishing areas due to pipelines both from platform to shore and between platforms. The effects of obstructions (such as unburied or spanned pipelines, rocks, etc. exposed by trenching, and debris from pipelaying activity and passing ships) on bottom fishing gear are also considered. The concept of pipeline trenching for safety and stability is discussed.

Finally, criteria to use in analyzing a proposed pipeline route are presented. Topics discussed include general industry siting criteria, geologic and environmental areas to avoid in pipeline siting and methods for minimizing unavoidable impacts.

This report is submitted in fulfillment of Interagency Agreement No. EPA-78-X0063 by the New England River Basins Commission under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period September 1, 1978 through March 1, 1979 and work was completed as of January 15, 1980.

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ACKNOWLEDGMENTS

My sincere appreciation goes to the report's principal author, Ann W. Gowen, who researched and wrote the majority of the document, and Michael J. Goetz, who prepared those sections of the report which deal with geologic concerns. Without their thorough research and diligent efforts, this report could not have been prepared.

Of the many other persons and organizations who have assisted in this project, we would like to thank those individuals in the oil and gas industry who provided valuable information and insight. In particular, thanks go to the Pipeline Industry Advisory Task Force (set up in cooperation with the American Petroleum Institute) and its Chairman, George G. Hughes, Jr., of Exxon Pipeline Company, who provided invaluable technical input to the project; and British Petroleum Company Limited (London), Shell U.K. Exploration and Production Limited (London), Brownaker Offshore (Norway), and Seditech (Denmark) for providing photos and information on their offshore activities.

Special thanks also go to John S. Farlow, Project Officer for the sponsor, the U.S. EPA's Industrial Environmental Research Laboratory-Cincinnati, for his continued advice and support; and Larry Shanks, U.S. Fish and Wildlife Service and Robert A. Matthews, U.S. Geological Survey for their insightful review of earlier drafts.

Irvin M. Waitsman
Manager, Coastal Programs

SECTION 1

CONCLUSIONS AND RECOMMENDATIONS

A number of lease sales of outer continental shelf (OCS) tracts for oil and gas development are now underway in areas previously not involved in offshore petroleum activity. Although in light of the world petroleum situation this type of development seems certain, apprehension is felt in these "frontier" areas regarding potential problems associated with offshore development.

One of the major sources of concern is the transportation of oil and natural gas from offshore platforms to the shore. Although pipelines are generally accepted as the safest method of oil and gas transportation, uncertainty is still felt regarding their possible effects on the locations chosen as pipeline routes. This project, sponsored by the U.S. Environmental Protection Agency (EPA), is designed to provide information on the environmental effects of OCS oil and gas pipelines to officials in frontier areas who may become involved in planning pipeline routes from offshore development areas to land. This document, "Choosing Offshore Pipeline Routes: Problems and Solutions," discusses environmental and fishing problems generally perceived to be associated with offshore pipelines. The report analyzes these problems, considering their causes, potential extent of impact, and where and/or when the impacts are likely to be the most severe. Industry's siting criteria, areas to be avoided in routing, and methods to minimize unavoidable impacts are described.

THE MAJOR ISSUES AND ROUTING SOLUTIONS

The major conclusion reached is that, in general, only small-scale, localized impacts will result from pipeline installation and operation. However, when choosing from among various routes, certain environmental and fisheries problems need to be assessed and their solutions compared to assure that the safest, most stable and most environmentally acceptable route will be delineated. There are two major environmental concerns associated with any pipeline siting decision: (1) leaks or spills of oil into ocean waters as a result of pipeline failures, and (2) potential damage to sensitive environmental areas on and near the pipeline route. Loss of access to fishing areas and damage or loss of fishing gear due to pipelines are the two major areas of potential impact on the offshore fishing industry.

These issues and some recommendations for lessening their potential effects are described below. Because the emphasis in this report is on minimizing the potential impacts through pre-planning and the route selection process, these "routing solutions" address primarily causes. Therefore, methods for minimizing the likelihood of a spill occurring rather than for minimizing a spill's effects are highlighted; likewise, methods of reducing potential fishing conflicts focus on lowering the chances of interference rather than on dealing with damages once sustained.

In addition, this report is an overview of potential effects associated with pipeline installation and operation and not a site-specific analysis of potential routes. The various geological, biological and fisheries issues described represent the full range of possible problems which may be encountered along a pipeline route. The solutions described represent a range of options available to minimize the potential effects of pipeline installation and operation. Area and site-specific issues such as the probability of a particular problem occurring or the severity of a particular problem have not been assessed.

Therefore, the issues raised and solutions discussed throughout the document can best be considered as a checklist to use in assessing potential problems and considering alternative methods for lessening their impacts along a specific route, rather than as an assessment itself. In the final analysis, any potential route will need to be evaluated individually. based on technical, environmental and economic criteria and appropriate mitigation measures chosen based on the characteristics of the route under consideration.

ISSUE #1--PIPELINE FAILURES WHICH RESULT IN LEAKS AND SPILLS

Problems

Of the four major causes of pipeline failures - corrosion, anchor dragging, bottom trawling equipment and unstable geologic conditions - geological conditions are the major concern which can be addressed during the route selection process. Because unstable geologic conditions affect a pipeline's safety and stability, industry's pipeline siting criteria are also based, to a large extent, on the geological conditions of proposed routes.

Solutions

Wherever feasible, geologically unstable areas should be avoided during the route selection process. Offshore these areas include: sand wave and scour areas, areas with unstable sediment conditions, and submarine canyon heads. Undesirable nearshore and shoreline geologic conditions include: high erosion rates, steep slopes (greater than ten per cent), rocks and very "spongy" wetlands. In addition, because neither burial nor artificial covering will protect a pipeline from large anchors, shipping corridors and other areas where heavy vessels may drop anchor should be avoided where possible. However, pipelines can and have been designed and routed through many of these undesirable areas, because other considerations, such as economics, have outweighed the technical construction difficulties.

ISSUE #2 - DAMAGE TO SENSITIVE ENVIRONMENTAL AREAS ALONG THE ROUTE

Problems

Offshore trenching, and trenching and burial at the landfall are likely to cause the greatest amount of environmental damage. However, when quantitative comparisons are made to other bottom disturbing activities, (bottom trawling, sea scalloping, etc.), it appears that pipeline trenching disturbs significantly lesser quantities of bottom sediments. Therefore, when assessing the potential extent of disruption to the ecosystems along a proposed route, the major consideration should be the type and sensitivity of the system to damage, rather than the quantity of disturbance. Because the coastal zone contains a greater array of diverse and frequently fragile habitats than offshore areas, special attention should be given to potential environmental effects nearshore and at the landfall.

Solutions

Key ecological areas and habitats should be avoided wherever feasible. These areas include: small, unique, or rare and endangered species habitats, spawning grounds, shellfish beds, wetlands, grassbeds and coral reefs. Once a route has been chosen, good construction and restoration techniques can further minimize the extent of damage. Techniques include: scheduling construction to avoid periods of highest biological sensitivity (e.g., spawning periods), installing the line in the shortest feasible period of time and restoring the disturbed area as soon and as close to original conditions as possible. Special techniques are also available to minimize installation problems in particular ecosystems, such as wetlands and sand dunes.

ISSUE #3--LOSS OF ACCESS TO FISHING GROUNDS

Problems

Both the gathering lines connecting platforms and the pipeline corridors from platforms to land may act as obstructions which block access to fishing areas. At the production area, unburied connecting lines and the safety zones generally established around platforms may eliminate as fishing areas both the pipeline rights-of-way and the inner waters between platforms. In addition, because of the risk of gear damage if hooked on exposed lines, fishermen may choose to avoid passing over a pipeline while trawling. Thus, the pipeline itself may prevent access by acting as a "dividing line" over which a vessel towing gear will not pass. Even in areas where the pipeline may originally have been buried, trawling directly over lines may not be advisable, based on past experience in which buried lines have become re-exposed. Therefore, when considering a potential route, attention should be paid to the location of major fishing areas, the trawling patterns of fishing vessels, and the extent to which access may be blocked due to offshore pipeline placement.

Solutions

Consultation with fishermen using offshore fishing grounds to be traversed by a proposed pipeline is the best way to minimize potential conflicts. While crossing fishing grounds may be unavoidable, consultations may reveal those areas most important to the fishing interests. Final routes can then be chosen based on avoidance of those subareas delineated by the fishermen as the most important portions of the larger fishing grounds.

Where these delineated fishing subareas cannot be avoided, technical choices regarding construction alternatives (e.g., premolded concrete coverings to provide additional protection) may be considered to allow trawling to occur over the line.

ISSUE #4--DAMAGE OR LOSS OF BOTTOM FISHING GEAR

Problems

This issue has two components: damage or loss of trawl gear on exposed pipelines and gear damage or loss on bottom debris present along a route.

It has been suggested that the possibility of trawl gear damage as a result of hooking on pipelines would be eliminated if the pipelines were buried - the current practice in nearshore and shallow areas (less than 200 feet deep). However, burial of pipelines in deep offshore waters (where bottom trawling takes place) has often proved difficult to achieve. Although a pipeline trench can be dug, many offshore areas have low bottom currents and little sediment movement, precluding natural backfilling and burial. Artificial backfill of pipeline trenches with crushed stone has been tried in the North Sea, and has proved expensive and inefficient. When a pipeline is trenched but not buried, it has been demonstrated that the risk of damage both to the trawl gear and the pipeline is significantly greater than when a pipeline is lying directly on the ocean bottom. However, even when the pipeline is trenched but not buried, the chances appear remote that trawl gear would hook, but not unhook--resulting in loss of gear.

On the other hand, damage is more likely to occur from bottom debris, which can rip or tear fishing nets. Bottom debris encountered along a pipeline route may come from three pipeline-related sources: bottom materials dug up during trenching; artificial stone cover; and debris from pipelaying operations and related vessels.

Solutions

The solutions to both these problems are, to a large extent, technological or engineering rather than routing-related. Avoidance of bottom fishing areas will eliminate the risk of trawl gear damage from pipelines. In deep offshore areas where this is not possible, an assessment of bottom current and sediment conditions may be necessary to determine the advisability of trenching and burial. Where natural burial is not expected to occur, it may be more advisable to lay the pipeline directly on the bottom (rather than in a trench), and then cover it with some type of additional protection (e.g., premolded concrete forms).

The issue of damage to fishing gear as a result of debris from pipelaying and other offshore activities is a difficult one, and one which will not be resolved by changing a pipeline's location. Although the effectiveness of various methods for lessening or limiting disposal of debris offshore are difficult to assess, current laws and regulations prohibiting dumping at sea may lessen the quantities of solid waste disposed in the future. In addition, when pipeline routing discussions are underway, consideration may be given to the possibility of stipulations in subcontracts to offshore service vessels prohibiting offshore dumping and stipulating vessel liability for cleanup if dumping does occur.

SECTION 2

DEFINING THE PROBLEMS--AN OVERVIEW

A number of lease sales for OCS oil and gas development tracts are now underway in U.S. offshore areas previously not involved in petroleum activity. Although in light of the world petroleum situation this type of development seems certain, much concern is felt in these "frontier" areas regarding potential problems associated with offshore development.

One of the major sources of concern is the transportation of oil and natural gas from offshore platforms to the shore. Currently, there are two methods for transporting oil: tanker/barge or pipeline. Due to the high cost of liquefaction, the only practical method of natural gas transport is via pipeline. In the U.S., pipelines transport all the natural gas and most (95%) of the oil produced offshore to land (Shanks, 1978).

Although pipelines are generally accepted as the safest method of oil and gas transportation, there are still a number of concerns regarding their possible effects on the locations chosen as pipeline routes. There are two major sources of concern: the environmental risks and the potential for interference with fishing activity. Environmental concerns focus on two areas: (1) leaks or spills of hydrocarbons from pipelines into coastal waters and (2) potential installation-related damage to sensitive environmental areas on and near the pipeline route. Fisheries-related issues include the potential loss of fishing area or gear due to pipeline placement and the resultant loss of fishing time, catch and revenue.

The anticipated effects associated with these problems are many. Oil leaks or spills*, particularly those which come ashore on sensitive coastal areas such as marshes, may cause extensive damage to flora and fauna whose recovery rates may be low. The laying of the pipeline on the seafloor can cause loss of nonmobile organisms directly beneath the line. Digging pipeline trenches in the seafloor can temporarily increase levels of suspended solids in the water column near the construction site and can result in altered habitat characteristics after the sediments settle. There may also be chemical and physical changes in the water column and sediment structure in the construction area. Depressions left in the seafloor due to the incomplete refilling of pipeline trenches may alter bottom water circulation patterns. Nearshore, pipeline installation may also cause short-term changes in water column characteristics due to resuspension of bottom sediments contaminated with toxic substances or with high concentrations of bacteria (which may lead to temporary localized decreases in dissolved oxygen concentration).

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*The effects of natural gas on marine ecosystems are generally assumed to be negligible because it is thought that leaking gas would bubble up through the water column and dissipate into the atmosphere. However, none of the literature examined to date has discussed this problem in detail, nor has mention been made of the effects of other constituents (e.g., hydrogen sulfide) which might be produced in association with natural gas streams.

Fisheries problems center on two particular issues: (1) the loss of fishing area along the pipeline route and its associated right-of-way, and (2) bottom obstructions which may cause fishing gear damage or loss. Even in areas where the pipeline may originally be buried, these issues still concern fishermen because past experience has shown that buried pipelines have become reexposed. The "loss of fishing area" issue is magnified at the production area itself, where gathering lines between platforms may effectively eliminate both the pipeline rights-of-way and the inner waters between the platforms as bottom trawling areas.

Bottom obstructions to fishing may include rocks and mounds of heavy clays exposed during the pipeline trenching operations in addition to assorted debris from pipelaying operations and passing ships. Trawling equipment may become exposed or hooked on unsupported segments of pipeline ("spans"). Even stone dumped on pipelines for cover may get caught in fishing nets, causing tears and possible loss. (These issues are examined in greater detail in Section 4--"Assessing the Fishing Problems.")

Before making an assessment of the potential impacts associated with environmental problems adjacent to a pipeline, it is necessary to understand what causes each problem and which of these causes can be taken into account during the pipeline route selection process.

CAUSES OF PIPELINE FAILURE

There are many suspected causes of pipeline breakage, including: anchor dragging; trawling; corrosion or other structural damage to the pipeline itself; and unstable geologic conditions along the pipeline route.

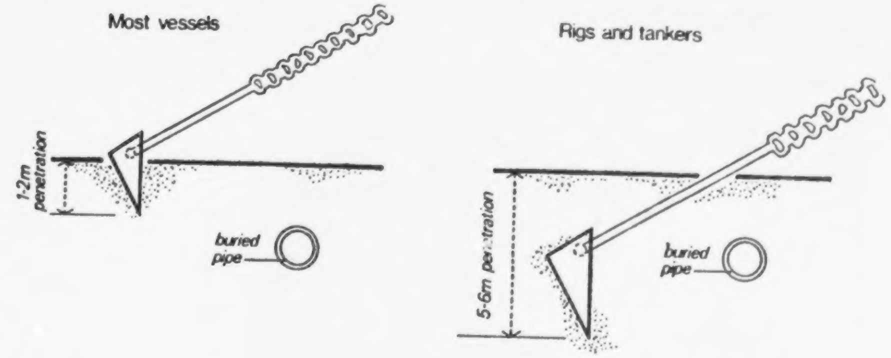
Anchor Dragging

Past experience in the Gulf of Mexico and the North Sea has shown that dragging anchors can hook on exposed and buried pipelines causing damage to the pipeline. In U.S. Geological Survey (USGS) records of Gulf of Mexico pipeline leaks (occurring from 1968-1978), of the 222 recorded incidents, 27 breaks were directly attributed to anchor dragging (USGS, 1978). In 1977, a 50,000 dead weight ton (DWT) tanker dragged its anchor across the Norpipe Ekofisk to Teesside oil pipeline approximately four miles offshore. This caused a five-inch dent and necessitated pipeline shutdown and repair (New England River Basins Commission [NERBC], 1979).

Protecting the pipeline from anchor dragging was one of many subjects considered in a comprehensive study undertaken prior to construction of the Far North Liquids and Associated Gas System (FLAGS) gasline. Shell Expro, the company which installed the pipeline connecting the North Sea Brent Field to St. Fergus, Scotland, commissioned a series of studies to determine the safest and most stable pipeline design and route. Three separate studies were undertaken (Shell U.K. Exploration and Production [Expro], 1977) to determine the risks of anchor hooking along the FLAGS line and the usefulness of burial for pipeline protection.

Study results indicated that the effectiveness of burial in protecting pipelines from anchors varies, depending on the type of anchor involved and how deeply the anchor penetrates into the sediments. Most commercial vessel anchors bury 0.5-3 meters (1.5 - 9.9 feet) into the sediment (Broussard, D.L. et al., 1978). Therefore, if a pipeline is buried and remains buried to depths of three meters or more, it would be protected from these anchors. However, in the case of oil-related vessels (such as pipelaying and derrick barge vessels) and large tankers, anchor penetration may be significantly deeper - from five to seventeen meters in good holding ground and even deeper in soft clays (Shell Expro, 1977). Figure 1 illustrates this point. Det Norske Veritas, a Norwegian company involved in safety and risk analyses of offshore structures, has also concluded that there is currently no effective way of preventing pipeline damage by large anchors, and, therefore, recommends that pipelines be routed to avoid areas of intense tanker or rig traffic (NERBC, 1979).

Besides pipeline burial, there are various structures available to protect pipelines laid directly on the seafloor from dragging anchors. For example, Seditech, a Danish firm, has developed and model tested the Coral HC2 system for protection of pipelines from objects dragging across the seafloor, in particular, ships' anchors. The HC2 system is constructed of premolded hinged concrete shields placed over a pipeline which detach when caught by a dragging anchor. The pipeline would remain protected, however, due to overlapping shield construction. If re-



Source: NERBC, 1979.

FIGURE 1. ANCHOR PENETRATION.

moved, a shield would have to be repositioned by diver or submersible. (These structures would also promote sediment deposition over the pipeline.) Figure 2 illustrates how the system works. With the exception of very large anchors, it is thought that this system would protect pipelines from anchor hooking.*

Trawl Gear

Concern has frequently been expressed regarding potential interference between pipelines laid through bottom fishing grounds and the bottom trawling gear utilized by fishermen--in particular, the large otter trawl doors used to keep bottom fishing nets spread apart. Figure 3 shows a typical otter trawl as it is approaching a pipeline. In a four year petroleum industry-sponsored program, VHL River and Harbor Laboratory at the Norwegian Institute of Technology examined this problem from both sides--i.e., the extent of damage to the pipeline and the extent of damage to the trawl gear as a result of gear/pipeline impacts. (Pipeline damage is considered here; results of fishing gear damage studies are presented in Section 4.) The following are the results of pipeline damage studies as presented in the Shell Expro FLAGS Study.

VHL determined that trawl doors could exert two types of force which could possibly damage a pipeline upon impact: (1) the impact force as the door hits the pipeline, and (2) the pull-over force as the door is dragged over the pipeline. Test

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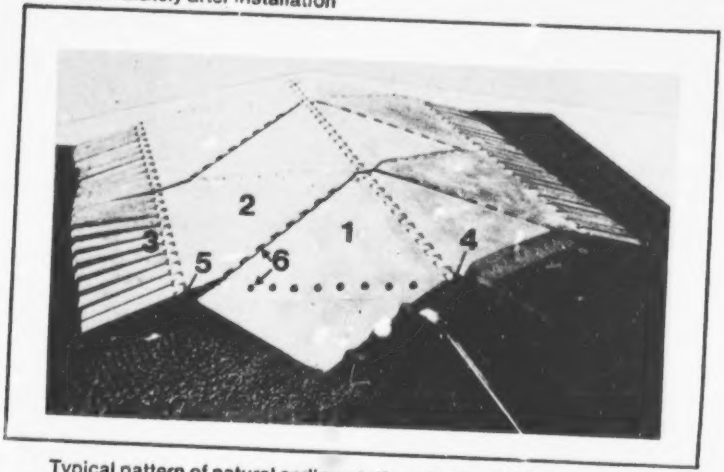
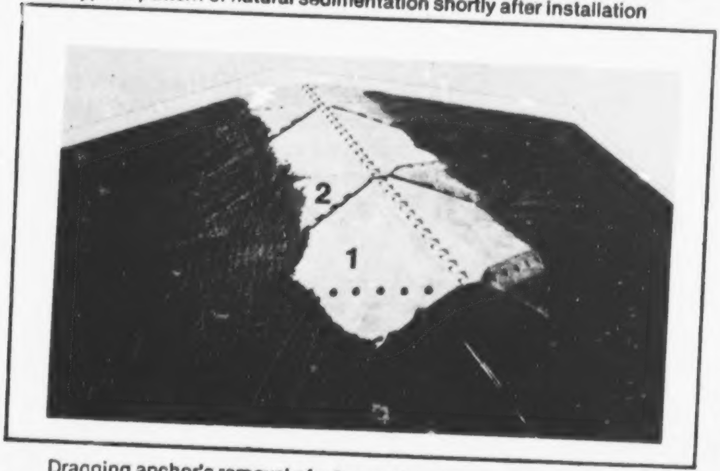
*O. Fjord Larsen, (Director, Seditech, Esbjerg, Denmark) 1978: personal communication.

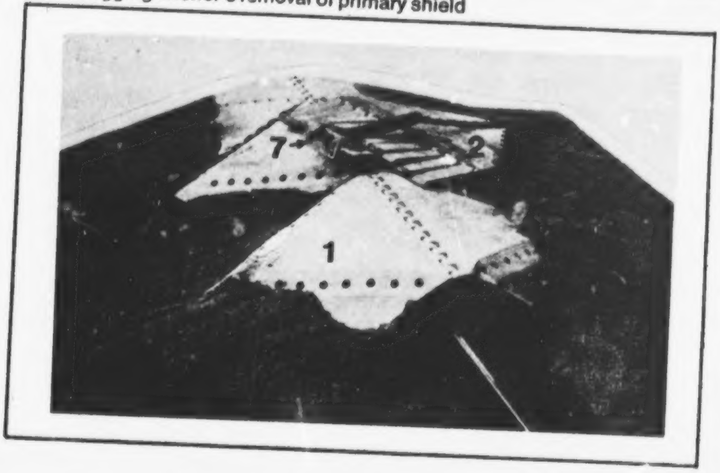
Immediately after installation



Typical pattern of natural sedimentation shortly after installation



Dragging anchor's removal of primary shield



1: Supporting cellular concrete module forming secondary shield in case (2) becomes removed by a ship's anchor.
By pivoting around the axle (4) the modules adapt to the irregularities of the seabed.

2: Triangular concrete plate forming primary shield against trawlboards and dragging anchors.
The plate resting loosely on (1) - only prevented from sliding downwards - a dragging anchor hooking the edge of (3) will remove (2) and ride on this over the top of (1), cf. lowermost photo

3: Concrete flaps hinged around (5). Within the individual module the mutual pivotal motion of the flaps is limited, so that the flaps together always form a continuous surface.
Due to their weight the flaps are in tight contact with the seabed, even if it is rugged. Crossing trawlboards therefore always pass over the cover without hooking the edge of (3).

4: Axle of several module lenghts.

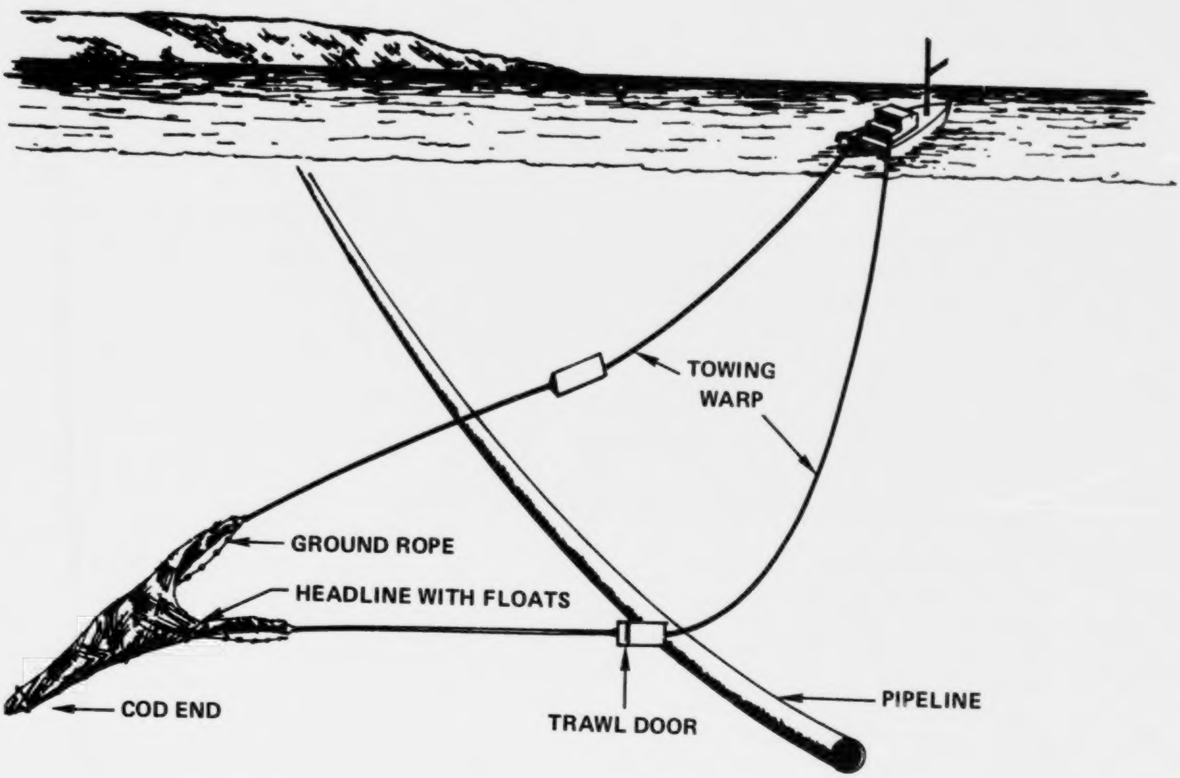
5: Axle of one module length.

6: Holes for neutralization of pressure differences.

7: Ship's anchor.

Source: O. Fjord Larsen, (Director Seditech, Esbjerg, Denmark) 1978: personal communication.

FIGURE 2. CONCRETE ANCHOR PROTECTION SYSTEM.


TOWING WARP
GROUND ROPE
HEADLINE WITH FLOATS
COD END
TRAWL DOOR
PIPELINE

Source: Carstens, 1977, p.7.

FIGURE 3. OTTER TRAWL

results indicated that the impact force from otter trawls of various sizes and shapes was insufficient to cause significant damage to the large diameter concrete-coated pipe used in the experiments. Damage is illustrated in Figure 4. Impact tests also showed no noticeable pipeline damage resulting from trawl boards weighing less than 1000 kilograms (2205 pounds). Pullover force results indicated a net lateral movement of the pipeline of less than 1.5 meters (4.92 feet) after multiple crossings (5) with trawl gear. However, pullover forces were significantly higher in cases where the pipeline was trenched than when lying on the ocean floor. From these studies, Shell concluded that concrete coating large diameter pipelines would provide more than adequate protection from trawl door impacts (Shell Expro, 1977).*

However, VHL test results did indicate that one type of bottom trawling equipment--the beam trawl--severely damaged the pipeline's concrete coating on practically every impact. This relatively new type of gear, used by Dutch fishermen, is designed for flatfish bottom fishing and is significantly heavier than otter trawl gear. Figure 5 illustrates this type of gear. VHL suggests that design changes in the beam trawl may alleviate the problem (Carstens, 1977).

Corrosion and Other Structural Problems

Corrosion is one of the major causes of leaks, particularly in older pipelines. Of the 91 recorded incidents of Gulf of Mexico pipeline leaks from 1976-1978 (USGS, 1978), 50 were attributed to corrosion. Corrosion prevention is generally addressed during the pipeline design process. The outside of the steel pipeline used offshore is first covered with a protective coating made of compounds such as asphalt, plastic or coal tar. Glass fiber may be used to reinforce this corrosion prevention coating. The pipe is then coated with reinforced concrete which is used to weight the pipeline and which offers additional external mechanical protection to the corrosion wrap and the pipe. In addition, chemical inhibitors may be injected into the system, if the composition of the products being moved through the pipe necessitates its use (for example, if the stream contains hydrogen sulfide or carbon dioxide plus water.**)

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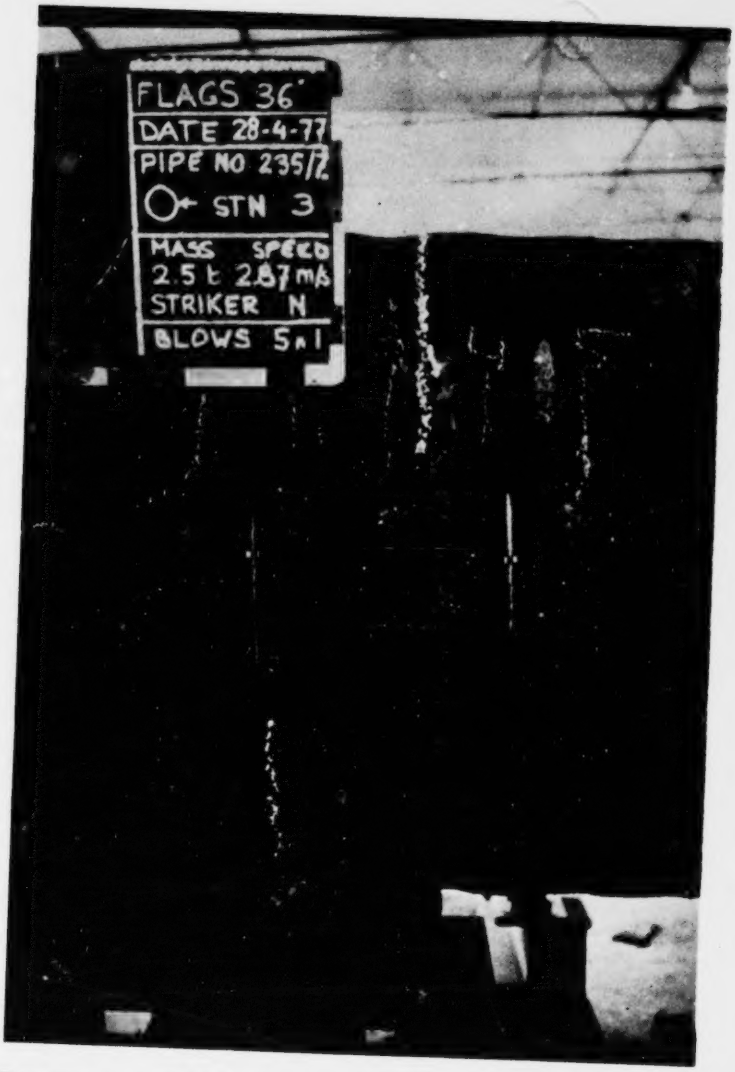
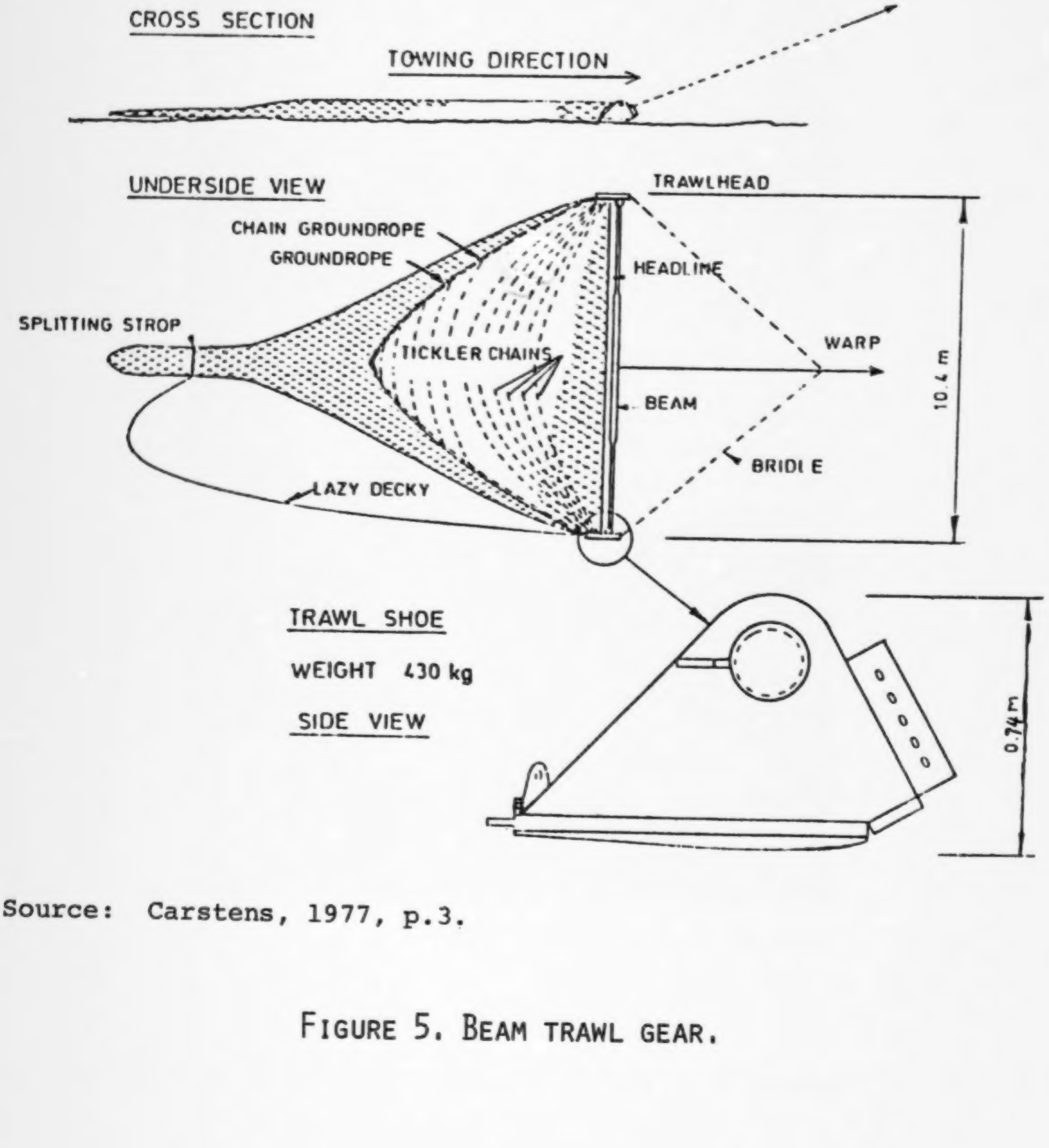
* On the other hand, small diameter pipe (as may be used in gathering lines), may not be as resistant to damage and may require additional protection beyond concrete coating. (A.D. Pinson [BP Trading Limited, London, England] 1979: personal communication.)

** George Hughes, (Exxon Pipeline Company, Houston, Texas) 1978: personal communication.


FLAGS 36"
DATE 28-4-77
PIPE NO 235/2
STN 3
MASS SPEED
2.5 t 2.87 m/s
STRIKER N
BLOWS 5 x 1

Source: Shell Expro, 1977, p.35.

FIGURE 4. DAMAGE TO PIPELINE CONCRETE COATING AFTER FIVE IMPACTS.


CROSS SECTION
TOWING DIRECTION
UNDERSIDE VIEW
TRAWLHEAD
CHAIN GROUNDROPE
GROUNDROPE
HEADLINE
SPLITTING STROP
TICKLER CHAINS
WARP
BEAM
10.4 m
BRIDLE
LAZY DECKY
TRAWL SHOE
WEIGHT 430 kg
SIDE VIEW
0.74 m

Source: Carstens, 1977, p.3.

FIGURE 5. BEAM TRAWL GEAR.

The potential for problems arising as a result of the use of pipe having manufacturing imperfections is minimal due to rigid design standards for liquid petroleum and gas pipeline systems set by the American Society of Mechanical Engineers and guidelines set by the American Petroleum Institute (API). (For complete specifications, see ANSI Publications B31.4 - 1974 Liquid Petroleum Transportation Piping Systems, ANSI B31.8 - 1975 Gas Transmission and Distribution Piping Systems and API RP 1111 Recommended Practice for Design, Construction, Operation and Maintenance of Offshore Hydrocarbon Pipelines - March, 1976.)

Geological Hazards

Pipelines may also be damaged by unfavorable geological conditions along an offshore pipeline route. Adverse geological conditions may result in exposure of previously buried pipeline, possible pipeline bending, and under sufficient stress, pipeline breakage. Numerous types of geological hazards are found offshore which may be grouped into two major hazard categories - sediment instability and seismic activity. Unstable sediments offer poor foundation support for pipelines and may lose their structural strength when shocked by an earthquake or intense wave activity. This loss of sediment strength may allow the pipeline to settle into the sediments, placing bending stress on the pipeline. Sediments scouring away from beneath offshore pipelines or eroding at landfall sites also cause additional stress on spanned or exposed lengths of pipe. Seismic activity may cause violent sediment displacement and can trigger large scale sediment mass movements which may cause spanning or breakage of a pipeline. While a pipeline may be structurally designed to withstand these geologic hazards to some extent, where possible these problem areas are avoided. When industry surveys each potential pipeline route, special emphasis is placed on the geologic nature of the area considered. This information is then utilized to choose a route which is the most safe and stable from a geologic viewpoint.

Preventing Failures--The Planning Issues

Of the potential causes of pipeline failure considered--anchor dragging, bottom fishing equipment, corrosion and geologic conditions--the following conclusions may be drawn regarding how each may be addressed during the process of choosing a pipeline route.

The problem of anchors hooking on pipelines may be partially solved by pipeline burial. However, this method is only effective for protecting against small ships' anchors and in areas where the pipeline is buried and remains buried at a sufficient depth. (Generally, burial greater than three meters [9.8 feet] would be sufficient to protect against small anchors.) Burial will not protect pipelines from the anchors of large vessels (such as tankers and pipelaying barges) which can penetrate up to 17 meters (55.8 feet) into the ocean bottom. Therefore, in planning a pipeline route, shipping corridors and other areas where heavy vessels may drop anchor should be avoided where possible.

Based on recent studies, the potential for damage to pipelines from bottom fishing gear is very small and may need to be considered in pipeline route planning (when considering pipeline failure prevention) only in areas where heavy beam trawls are utilized.

The potential for pipeline failures due to corrosion and/or structural imperfections is generally minimized in the design process in which pipeline specifications, coating and cathodic protection methods are chosen to accommodate those conditions under which the pipeline will operate.

Geologic hazards are the major cause of pipeline failure which can be addressed directly through the pipeline route selection process. Therefore, these hazards, their potential effects on a pipeline, and where they are the most likely to be encountered in offshore and coastal areas are discussed in greater detail in the Section 3--"Assessing the Environmental Problems."

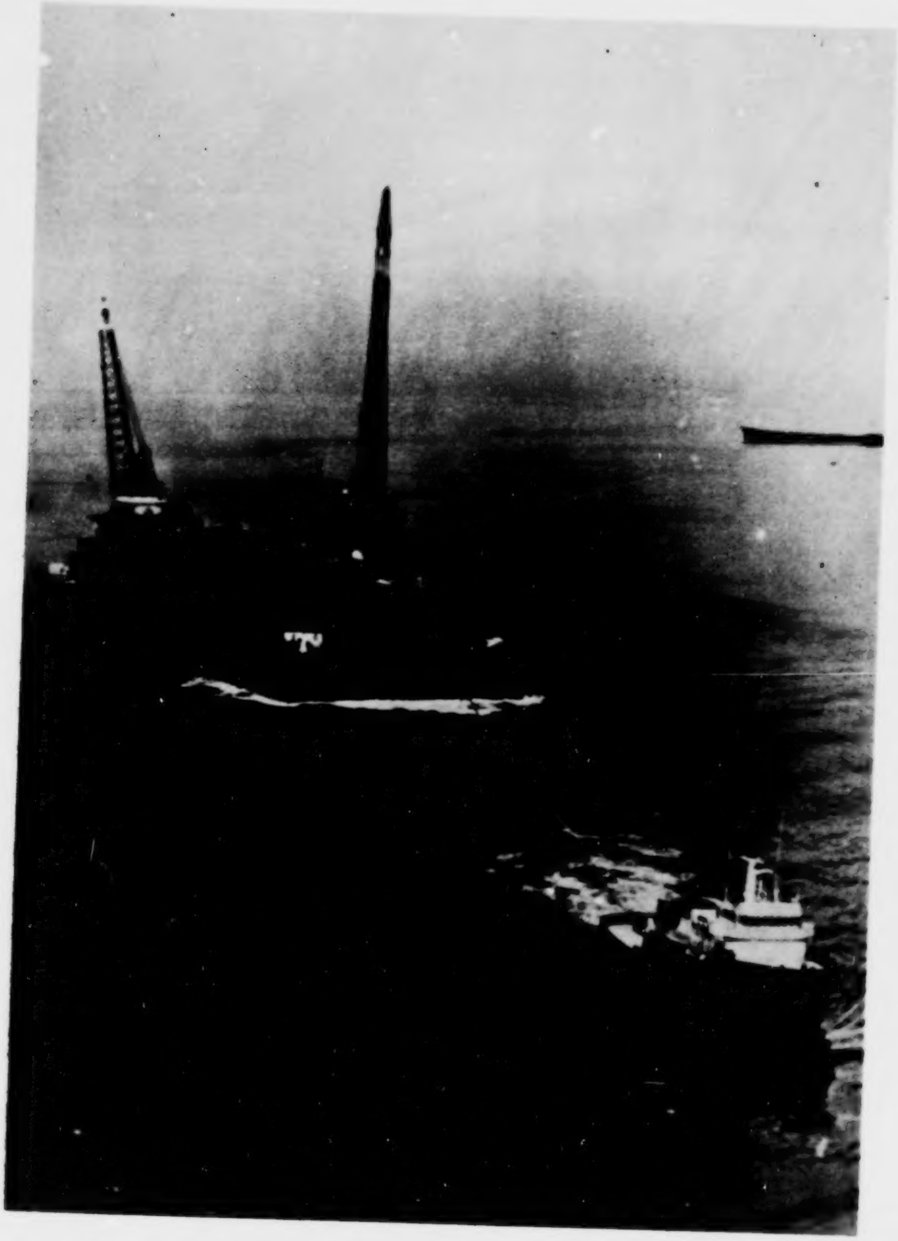
PIPELINE INSTALLATION--RELATED DISTURBANCES

Environmental disturbances along a pipeline route are caused by three separate phases of pipeline installation--laying the pipeline on the bottom, and if the pipeline is to be buried, digging the trench and burying the pipeline. Each phase of installation can be accomplished by various methods, depending on where the pipeline is being installed (offshore or nearshore/landfall) and the bottom conditions encountered. The type and extent of damage to the environment will also vary with the method utilized and the type of environment disturbed.

Offshore Installation Methods

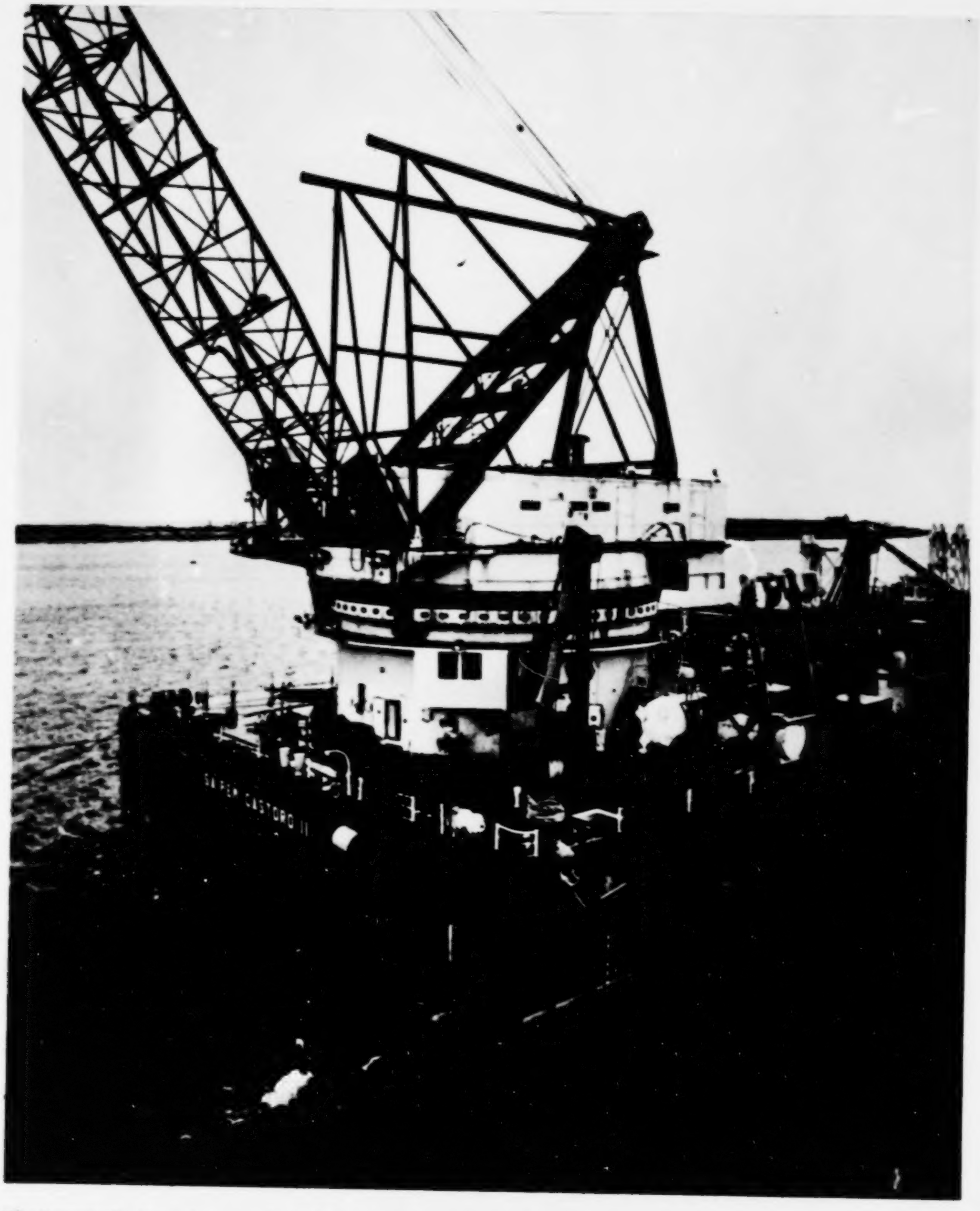
Pipelaying: Offshore pipelines are generally constructed of lengths of steel pipe which are coated with compounds for corrosion protection, and where necessary, concrete to provide sufficient weight to prevent flotation. Precoated pipe sections are welded together and the welds covered by mastic on a pipeline laybarge prior to lowering the pipeline to the seafloor. Two laybarge types currently used in the North Sea are shown in Figures 6 and 7.

As the pipeline is lowered to the seafloor, two bending stresses are exerted--one as the pipe leaves the laybarge (overbend) the other near the ocean floor (sagbend). To prevent overstressing, horizontal tension is applied to the pipeline and the



Photograph Courtesy of Brownaker Offshore A/S, 1978.

FIGURE 6. CENTER RAMP PIPELINE LAYBARGE.

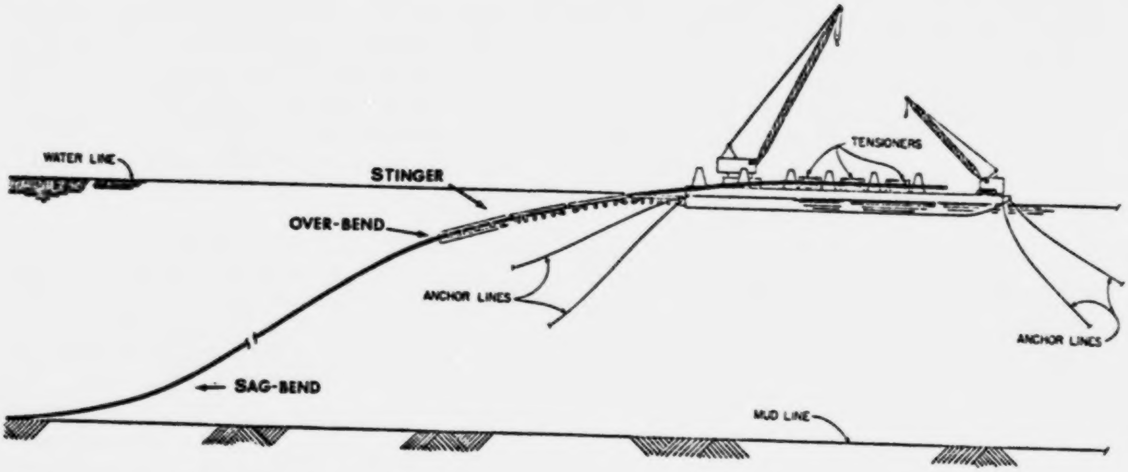


SAIPEM CASTORO II

Photograph Courtesy of British Petroleum, 1978.

FIGURE 7. SIDE RAMP PIPELINE BARGE.

pipeline is supported by a ramp ("the stinger") as it leaves the laybarge. Figure 8 illustrates this laybarge method of pipelaying.



Source: after Allen et al., 1976, p.64.

FIGURE 8. LAYBARGE METHOD OF PIPELAYING.

Offshore pipelines may also be laid using the reel barge technique. Pipe joints are welded, covered with protective coating, and inspected at a shore base. Pipe is wound onto a large reel on a pipelaying barge. The barge then moves to the pipelaying site where the pipe is unreeled, straightened and lowered to the ocean bottom. While this method allows the quick installation of given lengths of pipe because onboard welding, inspecting and coating operations are minimal, its use is currently limited to pipelines without concrete coatings and which have diameters of 16 inches or less.*

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*Pipeline Industry Advisory Task Force, 1979: personal communication.

Pipeline Trenching: If the pipeline is to be lowered into the seafloor, a trench must be dug. Three types of trenching machines are currently available: machines with rotating cutterheads which cut through the sediments; "jet sleds" which use high pressure water jets to "blast away" sediments; and plow type machines which push sediment aside as they are pulled across the bottom. The first two machines are lowered down and placed over the pipeline, which, after sediment removal, settles into the newly dug trench. In the case of plowed trenches, the pipeline is welded and coated onshore, the trench dug, and the pipeline towed to the site and placed in the trench. Suspended sediments from the first two trenching machines are sucked up into attached pipes and discharged above and to the sides of the trench; plow spoils remain on either side of the trench.

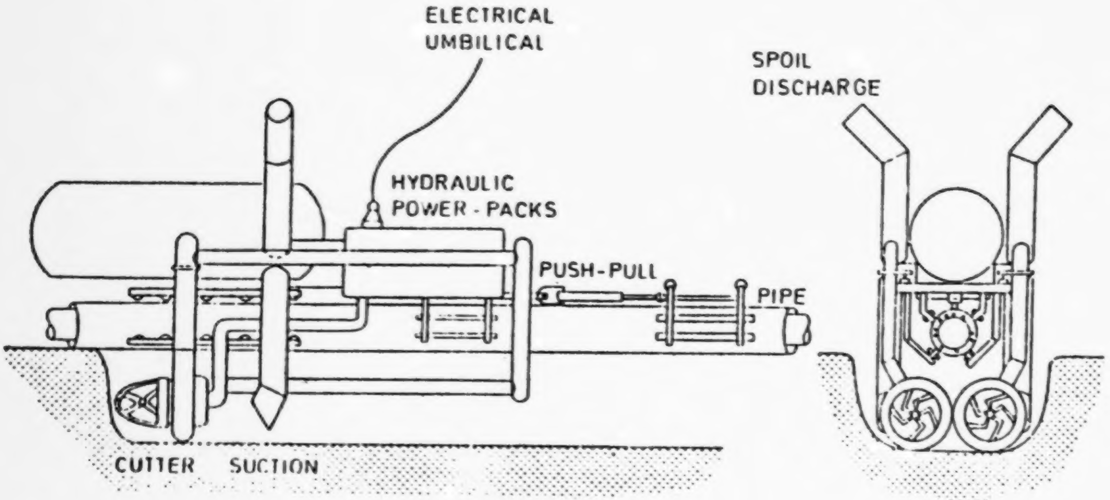
The rate at which a trench can be dug varies with the trenching machine used and the sediment types encountered. Cutterhead trenchers can dig a trench up to 2.5 meters (8.2 feet) deep. Reported trenching rates vary from 90-230 meters/hour (296-755 feet) in sand to 130-500 meters/hour (427-1640 feet) in clay (Norwegian Petroleum Directorate, 1978b).

Along the Forties Field pipeline, jet sled rates averaged approximately 1 kilometer/day (0.62 miles) in clay materials. While only one pass was necessary to dig the trench to the desired depth of 1.8 meters (6 feet) in clay, areas with sand and silt sediments sometimes required two passes of the jet sled. Rates in sand and silt averaged 3 kilometers/day (1.86 miles) with a peak rate of 5 kilometers/day (3.1 miles) (Walker, 1976).

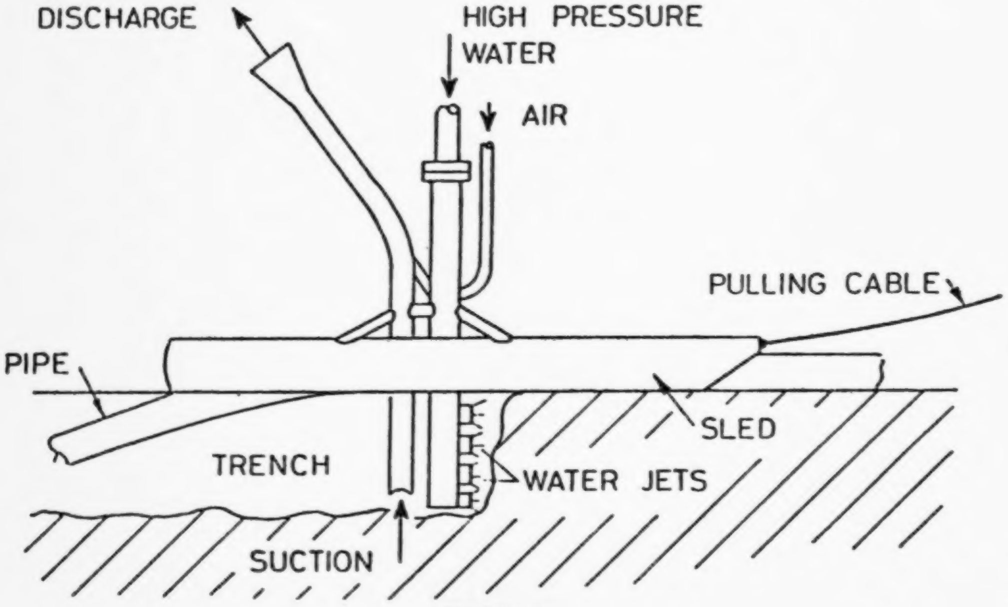
Because the plow technique is relatively new, its overall capacity is not yet known. However, one plow employed in the North Sea dug a 1.1 meter (3.6 feet) deep, 2.2 kilometer (1.37 miles) long trench through hard clay in 30 minutes (Underwater Plow Prepares Trench for Statfjord Loading Pipeline, 1977). Figure 9 illustrates these three trenching machines--a cutterhead type, a jet sled, and a plow.

The efficiency of any of these trenching machines and the width of the trench dug is based on the characteristics of the sediment being trenched and water depth. Trenches through clay sediments are generally narrow with vertical walls, while trenching through sandy sediments results in wide shallow trenches. In very muddy sediments, trenching may not be required as the pipeline may settle into the sediments under its own weight (Carstens, 1977).

Pipeline burial: Once pipelines have been laid, natural processes of current and wave action are generally relied upon to refill trenches. However, in some cases, for example, the North Sea Ekofisk to Emden, Germany gasline, artificial burial


ELECTRICAL
UMBILICAL
SPOIL
DISCHARGE
HYDRAULIC
POWER-PACKS
PUSH-PULL
PIPE
CUTTER
SUCTION

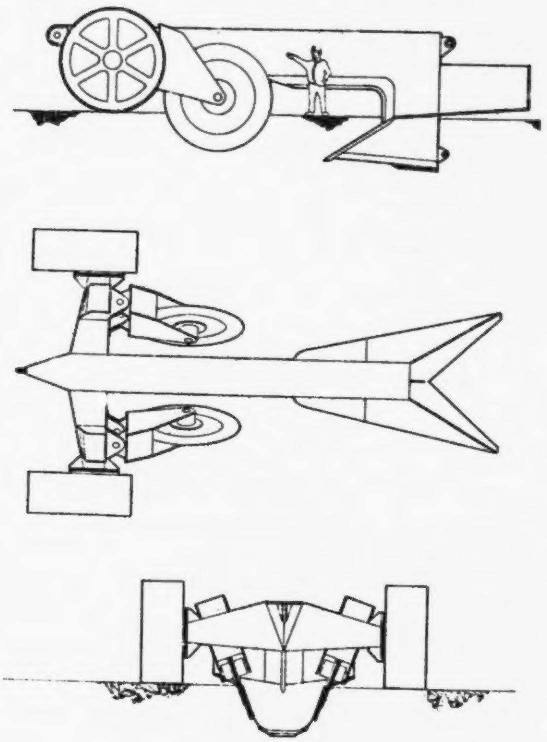
CUTTERHEAD


DISCHARGE
HIGH PRESSURE
WATER
AIR
PULLING CABLE
PIPE
SLED
TRENCH
WATER JETS
SUCTION

JETSLED

Source: Carstens, T., 1977, p. 4.

FIGURE 9. PIPELINE TRENCHING MACHINES.



PLOW

Source: Brown, R.J., 1978, p. 69.

FIGURE 9. (CONTINUED)

has been required. Crushed stone will be used in this case to cover exposed pipeline lengths (NERBC, 1979).

Evaluating the Usefulness of Trenching Offshore: Trenching and burial were originally prescribed for offshore pipelines, based on onshore and nearshore pipeline experiences, where burial provided the benefits of increased safety and stability. For example, in the North Sea, all but one of the major pipelines have been or are being trenched and buried. However, extensive problems were experienced in attempting to bury the Ekofisk to Emden pipeline, where numerous passes were often required to dig the trench (averaging 3.2 passes to reach the desired depth) and where subsequent inspection revealed that in many places natural backfilling had not occurred. Based on these and other problems experienced in attempting to bury North Sea pipelines, Shell Expro, as part of its comprehensive study on the FLAGS gasline, initiated studies to test the validity of the assumption that trenching would provide added safety and stability to deep water offshore pipelines. The following are the major conclusions from that study (NERBC, 1979):

- bottom currents are insufficient in deep water areas to provide sediment transport and resulting natural burial;

- trenches cut in the soft sediments which characterize deep water areas tend to have a wide profile rather than a narrow, well-defined profile;

- current technology in concrete coating and steel reinforcing is such that a trawl door will cause no more than a scratch (16 millimeters [0.6 inches] deep) on the pipeline coating and damage to the pipe will not occur;

- trawl doors sliding into a shallow or wide profile trench have more chance of being damaged than if the pipe had been laid directly on the sea bottom; and

- burial will not protect a pipeline from dragging rig or tanker anchors.

Shell Expro concluded: "Trenching in deepwater is not necessary for stability; it provides no additional mechanical protection, and furthermore, it caused an increase in the risk of damage to fishing gear." (Shell Expro, 1977. p.i.) Based on their results, Shell Expro applied to the United Kingdom (UK) Department of Energy for approval of the FLAGS gasline, trenching only where additional stability was needed, such as nearshore areas subject to strong bottom currents and storm-induced wave effects. Approval was granted for the pipeline (which was completed in June, 1978) with trenching required only in these unstable nearshore areas.

Not all North Sea operators agree with the conclusions drawn from these experiments. BP, for example, contends that pipelines which are trenched, but not buried, are marginally better from a risk viewpoint than those which are lying directly on the ocean bottom.*

A final observation regarding offshore trenching is that the repeated passes by trenching machines required in many types of offshore sediments to dig trenches of sufficient depth, can cause physical damage to the concrete coating on the pipeline. This loss of coating may occur as the sled is raised or lowered over the pipeline or as a result of the high pressure water jets which may loosen already cracked concrete (Broussard et al., 1978).

Nearshore/Landfall Installation Methods

Pipelines laid in nearshore waters and at the landfall site are always required to be buried. As the water depths become too shallow for use of offshore equipment, modified techniques are used.

Pull Technique: This technique (also known as the "push" or "push/pull" technique) requires a fairly firm shoreline, such as a sand or gravel beach, in which a small canal four to six feet deep and eight to ten feet wide is dredged. Sheetpile retaining walls are often used to maintain the canal during construction. Sections of pipe are welded onboard a laybarge which moves as close to the landfall site as possible. Using onshore winches, the pipe is pulled into the canal and onto land. The canal is then backfilled. A right-of-way as large as 150 feet (Conner et al., 1976) to 250 feet (U.S. Coast Guard [USCG], 1976) may be required. This method was utilized successfully at the landfall for the 36" gasline from the Brent to St. Fergus, Scotland, and for the 48" lines coming ashore across a barrier beach from the Louisiana offshore port (LOOP) deepwater project. Figure 10 illustrates this installation method.

Flotation Technique: The flotation technique is used at soft or unstable landfalls, such as marshes. Because this type of terrain cannot support the weight of pipe** and onshore lay-

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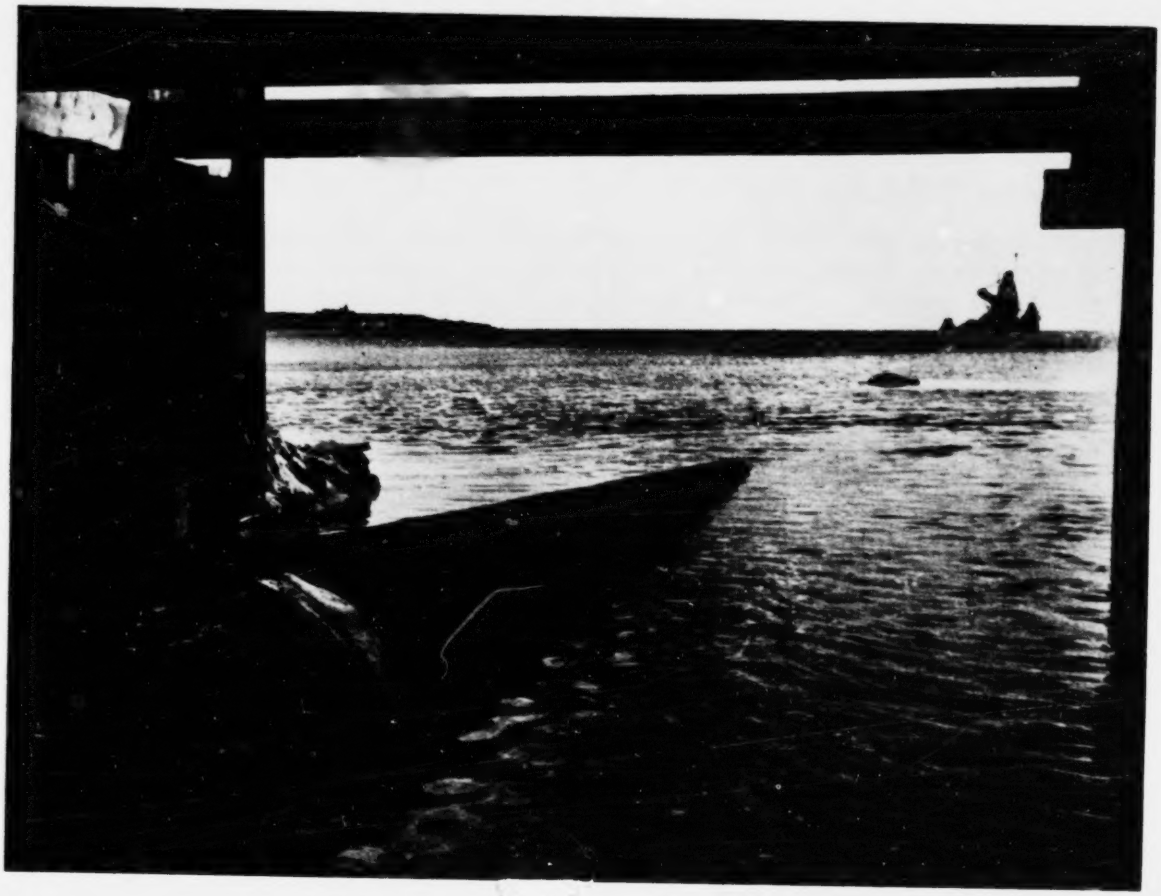
*H.D. Pinson, (BP Trading Limited, London, England) 1979: personal communication.

**A 40 foot section of 36-inch uncoated pipe weighs approximately 8,000 pounds; when coated with three to four inches of concrete, a section may weigh up to 34,000 pounds.



Photograph Courtesy of British Petroleum, 1978.

FIGURE 10. "PULL" TECHNIQUE OF PIPELAYING.

ing equipment, a canal is dug so that conventional shallow water pipelaying equipment may be used. Canals which may be 40 to 50 feet wide and six to eight feet deep are dug inland from the shoreline by barge-mounted dredges. An additional trench for the pipeline may be dug on the canal bottom. Offshore flatbottom barges can then move into the canal, laying the pipeline using the "stovepipe" or reel barge technique. This method may require a right-of-way from 300 feet (Conner et al., 1976) to 450 feet (USCG, 1976) wide.

Environmental Disturbances from Pipeline Installation

There are four types of pipeline installation-related environmental disturbances which may occur along and adjacent to a pipeline route. These disturbances are: loss of organisms; increased turbidity; habitat alterations; and physical and chemical changes.

Where pipelines are untrenched, as may occur in deep offshore waters, impacts will generally be minimal. Small numbers of organisms directly beneath the pipeline will be lost and slight increases in turbidity may be experienced as the pipeline touches bottom. No changes in circulation patterns and the overlying water's chemical composition would be expected from unburied pipe. In addition, unburied pipelines, like other offshore structures, may offer new habitat to colonizing species attracted to this new "artificial reef."

If trenching and burial occur, either offshore or in the shoreline/landfall area, more extensive effects may be expected. Trenching will displace those organisms living on the bottom and in the sediments and will introduce suspended materials into the water column as a result of jetting or dredging the trench or canal. For example, a short-term but tenfold increase in turbidity was predicted as a result of trenching the LOOP project pipelines (USCG, 1976). In some cases, this "mixing" may have positive effects by creating a new temporary feeding ground for water column and suspended benthic fauna.* If resuspended sediments are contaminated with toxic chemicals or bacteria, the chemical composition of the water column immediately above the pipeline may be temporarily affected. Resettlement of sediments may alter habitat characteristics and lead to changes in local species composition at and near the pipeline. Incomplete refilling of offshore pipeline trenches may cause depressions in the seafloor, possibly altering bottom circulation patterns. Incomplete restoration of landfall sites may result in "weak links" (areas of low resistance to physical stress) along a shoreline which may be destroyed during storms, or may change hydrologic patterns in a wetland.

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*H.E. DeGreenia, (Tennessee Gas Pipeline, Houston, Texas) 1979: personal communication.

The Extent of Environmental Disturbances

Although it is possible that pipeline installation, and in particular, trenching, will cause some environmental damage, there are other offshore activities which may produce comparable disturbances. For example, comparisons are possible between the amount of bottom sediment disturbed by pipelining and other non-oil and gas-related offshore activities. These activities include offshore bottom fishing using otter trawls, surf clamming with hydraulic dredges or sea scallop harvesting, and offshore dredge spoil disposal. Table 1 illustrates estimated amounts of sediment disturbed by these activities compared with projected amounts of sediment disturbed by pipelaying activity.

TABLE 1. SEDIMENT DISTURBANCE BY SELECTED OFFSHORE ACTIVITIES

		Equivalent miles of pipeline[a]		
		Lease sale 42 EIS for Georges Bank	FLAGS report	
Activity	Amount of Sediment Disturbed (millions of cu yd/year)		Narrow	Wide
Surf clamming	486[a]	61,000	30,000	11,000
Sea scallops	158[a]	19,750	9,753	3,718
Otter board trawling	170[a]	21,250	10,494	4,000
Dredging	520[b]	46,250	22,840	8,700

[a] Calculations are based on 100 boats working 100 days per year. See Appendix I for additional assumptions and calculations.

[b] Shanks, 1978, p.5.

Source: NERBC, 1978

The final columns in Table 1, miles of pipeline, are based on three different trench profiles: Georges Bank Lease Sale 42, Environmental Impact Statement (EIS) which estimated 8,000 cubic yards (cu yd) of sediments disturbed per mile of pipeline; and two trench profiles diagrammed in the FLAGS report (p.21). A trench dug in clay with vertical walls was estimated to disturb 16,262 cu yd of sediment per mile of pipeline dug. A shallow, wide trench produced in sand was estimated to disturb 42,504 cu yd of sediment per mile of pipeline. (See Appendix A for calculations.) These three trenches were chosen to represent a variety of sediment conditions and thus a variety of trench profiles which might be encountered in laying an offshore pipeline.

Even when considering the widest trench profile in which the largest estimated quantities of sediment are disturbed, annual disturbances by other offshore activities, such as dredging and bottom fishing, are equivalent to 4,000 to 11,000 miles of pipeline trenching. By comparison, there are approximately 2,000 miles of oil and gas pipelines in the Barataria Bay region of the Gulf of Mexico and approximately 1,750 miles of offshore pipelines in the entire North Sea offshore development area.

Environmental Disturbances--The Planning Issues

Of the various phases of pipeline installation, offshore trenching, and landfall trenching and burial operations are likely to cause the greatest amount of environmental disturbance. But when compared with other types of offshore bottom-disturbing activities, the relative quantities of sediment disturbed by trenching are significantly less. In addition, the surface area disturbed by trenching would be small and would affect only a narrow corridor through a number of habitats. In comparison, fishing activities disturb large portions of specific areas (fishing grounds). While pipeline laying is a one-time event, fishing in certain areas is a reoccurring one. In addition to man's activities, natural phenomena such as storm and tidal action will also suspend and rework bottom sediments. It appears, therefore, when considered quantitatively, that only small-scale localized environmental alterations will occur as a result of pipelaying activities.

Therefore, the major conclusion regarding installation-related disturbances is that it is the character of the environmental system disturbed (rather than the degree of disturbance) that will determine the impact. For example, a pipeline laid through a small or unique habitat will cause a significantly greater impact than one passing through a large, environmentally homogeneous bottom area.

These sensitive environmental areas can be identified and, where possible, should be avoided during the pipeline route selection process. Therefore, further discussion will focus on the types of systems which may be the most severely impacted by pipeline installation-related disturbances, and where these systems are likely to be encountered offshore and at the shoreline landfall.

SECTION 3

ASSESSING THE ENVIRONMENTAL PROBLEMS

To minimize environmental damage from offshore pipelines, the safest and most stable route from the production area to the shore must be located. To do this, it is first necessary to assess each potential route, identifying those features which are most likely to have an impact on or be impacted by the pipeline's installation. As concluded in the previous section, two major factors should be considered in this assessment:

- the geological characteristics of the route. Sediment conditions and the seismic nature of the area will affect the stability of the pipeline, which will, in turn, determine its susceptibility to structural damage and possible leakage or failure; and
- the characteristics of the ecosystems along the route. Each system's sensitivity to various environmental disturbances will determine the extent of impact resulting from pipeline installation.

This chapter will consider these factors, highlighting why each is important and indicating where each is most likely to be encountered along a pipeline route.

GEOLOGIC HAZARDS

The geologic nature of the OCS and coastal zone has a definite influence on the routing of pipelines in these offshore areas. The presence of thick layers of sediments, a high degree of sediment variability and the constant modification of sediments by wave and current activity could result in sediment instability that would be hazardous to pipeline installations. The major forms of sediment instability include: variable sediment conditions (changes in the physical and engineering properties of sediments), liquefaction (a type of bearing strength loss), pipeline flotation in fluid sediments, sediment scour, sand waves, and shoreline erosion.

The seismic characteristics of these regions may also influence pipeline routing. The presence of active faults in an OCS region would present several potential hazards to pipeline construction and operation including: fault movement, tectonic deformation; ground motion (shaking); earthquake-induced sediment failures; and sediment mass movements.

Sediment Conditions

The Problems: The capability of the ocean floor to support an offshore pipeline depends, in part, on the characteristics of the sediments found along a proposed route. Sediment strength varies from extremely weak (e.g., sediments made up of poorly consolidated silts) to very strong in areas where dense sands are present.

Fine, poorly consolidated silts (grain size 0.0625 - 0.004 millimeters), clays (less than 0.004 millimeters) and muds (mixtures of silt and clay) will generally provide poor structural support. These sediments are often deposited in a loose, "honeycomb-like" framework, which retains large quantities of water. With slow settling and compaction, the pressure of the trapped pore water increases, resulting in an overall decrease in the sediment strength. Pore pressure may also be very high where the deposition of fine sediments is rapid. In either case, little force is required to cause sediment failure (a breakdown in the sediment's structure and the resulting loss of strength) (Blatt et al., 1972).

Generally, as cohesion between sediment particles increases, sediment strength and bearing capacity also increase. Increased cohesion results when the clay content of fine sediments is high. Attractions between individual clay grains (cohesive forces) cause the sediments to "stick together." Highly compacted clays with numerous grain-to-grain contacts have increased numbers of cohesive bonds, and greater sediment strength (Wilun and Starzewski, 1972). Compact, cohesive clays often have good structure-bearing capacity because of this increased strength.

Dense, fine-to-medium sands should provide excellent support for structures placed on them. Although slightly weaker, sands interlayered with stiff, compact clays should also be capable of supporting a pipeline.

Areas most likely to be affected: Fine-grained, cohesionless sediments which have very low bearing strength may pose problems in pipeline siting. Areas where these sediment types are most likely to be found include:

- lagoons, estuaries, wetlands and deltas. Deltas are particularly hazardous because, in addition to unfavorable sediment type, deposition is rapid, forming a loose, very unstable sediment framework; and

- quiet, deep sections of the continental shelf and slope.

In addition, where poorly consolidated clays and patches of lagoonal muds underlie surficial sands, the weight of a pipeline could cause the underlying fine sediments to compact or fail, resulting in local seafloor settling and subsequent pipeline damage (Bureau of Land Management [BLM], 1976).

Liquefaction

The Problems: Liquefaction occurs when a sediment's grain-to-grain structure is broken down, causing it to more closely resemble a liquid than a solid. Sediment strength is reduced when "liquefied," and the capability of foundation sediments to support a pipeline is lessened.

Rapid deposition of coarse silts and fine sands results in the formation of a loosely packed, unstable structure in which the pore water bears a large amount of weight normally supported by sediment grains. A wave or seismically induced shock can break down this structure causing the pore water to support almost all of the sediment grains; the sediment, in effect, becomes a liquid with little or no strength.

Areas most likely to be affected: Table 2 shows the estimated susceptibility to liquefaction of sedimentary deposits associated with the continental shelf and coastal zone. Generally, locations with large quantities of recently deposited cohesionless sediments are most affected.

TABLE 2. SUSCEPTIBILITY OF SEDIMENT DEPOSITS TO LIQUEFACTION

	Susceptibility of Saturated, Cohesionless Sediments to Liquefaction (by Age of Deposit)			
Type of deposit	<500 yr.	Holocene (500-10,000 yrs.)	Pleistocene (10,000-3 million yrs.)	Pre-pleistocene (Greater than 3 million yrs.)
Delta	Very high	High	Low	Very low
Estuarine	High	Moderate	Low	Very low
Beach				
High wave energy	Moderate	Low	Very low	Very low
Low wave energy	High	Moderate	Low	Very low
Lagoonal	High	Moderate	Low	Very low
Foreshore	High	Moderate	Low	Very low
Uncompacted fill	Very high	--	--	--
Compacted fill	Low	--	--	--

Source: after Youd and Perkins, 1978. p.441.

Pipeline Flotation

The Problems: Fine sediments (especially silts, muds and clays) slowly backfilling a trench can mix with water to form a dense, heavy fluid with little or no strength. A pipeline having a specific gravity lower than this fluid would float to the sediment/water interface (mud line). The backfill of the trench may also be converted to a liquid state by liquefaction. If liquefaction occurs directly below the pipeline and the pipeline has a higher specific gravity than the resulting fluid, the pipeline will sink further into the liquefied sediments.

Areas most likely to be affected: Fine-grained sediments are most likely to form a fluid trench backfill. Areas where these sediments types are likely to be found include:

- lagoons, estuaries, wetlands and deltas; and
- quiet, deep sections of the continental shelf and slope.

Those areas that are susceptible to liquefaction may also be subject to floating pipelines (see Table 2).

Sediment Scour

The Problems: The removal of sediments from around a buried pipeline by scour would expose the line to stresses from wave and current activity which could cause pipeline damage. Where large quantities of sediments are removed from beneath the pipeline, spans (suspended lengths of pipe) may result. A spanned pipeline would be subject to additional stresses from sagging and from the flow of water around the line. With sufficient current velocity, the pipeline may begin to vibrate, resulting in damage to the pipeline or its concrete coating. Pipeline vibration failures have occurred in Cook Inlet, Alaska, in areas where pipelines are not buried and are exposed to high velocity tidal currents (Ralston and Herbich, 1968). Pipeline vibrations may have also been the cause of a line losing its concrete coating and floating to the surface at Yell Sound in the North Sea area (Guerry, 1976).

Water flowing over the seafloor exerts a force on the individual sediment grains which tends to cause movement. The current velocity necessary to initiate sediment movement is called the threshold velocity and is primarily dependent on the grain size of the sediments. Fine-to-medium sand (0.1-0.5 millimeters) generally requires a current velocity on the order of 15 to 50 centimeters (0.5 to 1.5 feet) per second. Coarser sands (0.5-2.0 millimeters) begin movement at current velocities of 20 to 100 centimeters (0.6 to 3.3 feet) per second while very coarse sands and gravel require velocities in excess of 100 centimeters (3.3 feet) per second.

Although fine grained sediments might be expected to have lower threshold velocities than coarser sediments, experiments have shown that as grain size decreases below 0.18 millimeters (fine sand) threshold velocities begin to increase for some mixtures of sediments. Well-compacted, fine sediments produce a smooth ocean bed, which reduces friction and increases cohesive forces, which may, in turn, cause these increased threshold velocities (Inman, 1963). Fine-grained clays (0.001-0.002 millimeters) can have threshold velocities as high as 500 centimeters (16.4 feet) per second (as much as required for some sizes of gravel). Soft, loosely structured muds have lower threshold velocities resulting from low cohesion, poor compaction and high water content. Figure 11 illustrates the range of threshold velocities for different sediment sizes.

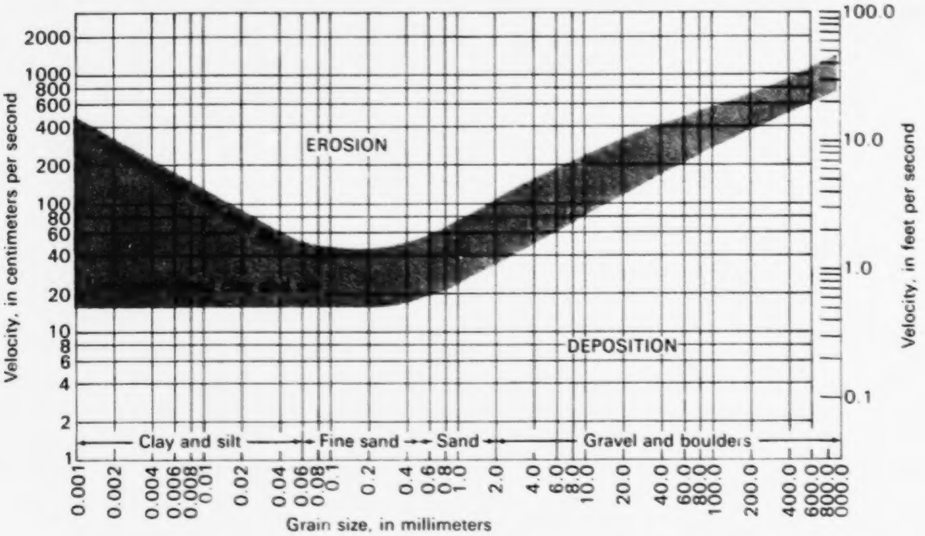
Areas most likely to be affected: Shallow approaches to the nearshore and shallow sections of the continental shelf where wave and tidal current activity are high are most likely to be subject to scour. Tidal currents on Georges Bank in the North Atlantic OCS may approach velocities of 90 to 200 centimeters (3 to 7 feet) per second--enough to move most sizes of sand (BLM, 1977). Shallow water storm waves may also produce significant bottom velocities. A storm wave 23 feet high in 30 feet of water could produce a bottom velocity of approximately 425 centimeters (14 feet) per second under the wave crest (BLM, 1977).

Sand Waves

The Problems: There are two basic concerns associated with the presence of sand waves: the size of the features may present a physical obstruction to pipeline construction activity; and sand wave movement may uncover buried pipelines or subject the pipeline to spanning.

Sand waves (also called sand or tidal ridges), which cover large sections of the North and mid-Atlantic OCS, average 7 kilometers (4 miles) in length and range as high as 30 meters (98 ft.) in height. Slopes of 17 degrees have been measured in places on Georges Bank (Offshore Navigation, Inc., 1976).

Sand waves can be highly mobile features. Their direction of net migration appears to be associated with the direction of ocean wave approach. For example, on Georges Bank, ocean waves approaching primarily from an easterly direction caused a general westward migration of approximately 300 meters (975 feet) over a 25 to 28 year period (BLM, 1977). Various researchers have reported yearly movements of 69 meters (225 feet) off Vir-



Source: Sundborg, 1956.

FIGURE 11. THRESHOLD VELOCITIES FOR SEDIMENT PARTICLE MOVEMENT.

Curve showing slowest velocity of flow at which sedimentary particles (quartz in sand sizes, other material in coarser and finer sizes) begin to erode. The width of the dark band indicates approximate variations, depending on water depth and cohesiveness of material. Note that fine sand (0.08 to 0.5 mm in diameter) erodes most readily; both finer and coarser materials require greater velocities. These curves are based upon experiments with carefully sized materials, not upon mixtures of a wide size range.

ginia with single storms causing movements of as much as 82 meters (250 feet) (BLM, 1976).

There are differing opinions on the effects of sediment movement (scour and sand waves) on offshore structures. It has been suggested that the thick accumulation of sand around the legs of the Texas Towers (part of an offshore early warning radar system) on Georges Bank sufficiently weakened these structures to cause their abandonment and eventual removal (Emery and Uchupi, 1972). Other sources indicate that the Texas Towers were removed only because they were obsolete and that proper engineering and maintenance can ensure the safe operation of structures in areas of sand movement.*

Areas most likely to be affected: Sand waves are generally found in shallow areas of the continental shelf (less than 60 meters - approximately 200 feet deep) which are subject to swift tidal currents and intense ocean wave activity. While sand waves found in deeper regions of the shelf are probably relict features and nonmobile, some sand waves have been discovered near the head of Wilmington Canyon on the mid-Atlantic OCS in 70 to 100 meters (230 to 330 feet) of water that appear to respond to storms and current flow in the canyon head (BLM, 1979).

Shoreline Erosion

The Problems: Shoreline erosion is a particular concern when choosing a landfall location for a pipeline. To protect the pipeline from exposure to the intense wave and current activity of the beach and nearshore, it is essential that the pipeline remain buried below the level of expected erosion. Shoreline erosion can be caused by one or more of the following factors:

- a reduction in longshore sediment supply. Sediments may be trapped by man-made obstructions (stabilized bluffs, jetties, groins, etc.) or natural obstructions (tidal inlets, estuaries, etc.);
- storm wind and wave activity. Permanent shoreline erosion appears to be associated with storms occurring every one and one-half years (Nordstrum et al., 1978);
- shoreline developments. Modifying coastal areas through grading or drainage may cause disruptions and changes; and
- sea level rises.

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*Pipeline Industry Advisory Task Force, 1979: personal communication.

Areas most likely to be affected: Erosion is a major problem associated with most beaches and barrier beaches in the United States; however, the following areas are generally most susceptible to shoreline erosion:

- beaches and barrier beaches exposed directly to winds and ocean waves;
- beaches and barrier beaches downdrift from obstructions to the natural longshore movement of sediments; and
- coastal cliffs or bluffs cut in unconsolidated sediments.

Those coastal areas least susceptible to shoreline erosion include:

- protected bays and estuaries;
- rocky shorelines; and
- beaches not directly exposed to ocean waves.

Seismic Hazards

The Problems: Fault movement may be vertical, horizontal or a combination of both. Slight movement may place stresses on a pipeline, but it has been estimated that a pipeline constructed over a fault could withstand a vertical displacement of 15 to 25 feet before failing (Arnold, 1967).

The large scale horizontal or vertical movement of the earth's crust is known as tectonic deformation. During the 1964 Alaska earthquake, elevation changes averaged six feet over an area of between 70,000 and 110,000 square miles of seafloor and land in southern Alaska. In some isolated areas vertical changes amounted to nearly 50 feet (Nichols and Buchanan-Banks, 1974).

The intensity of ground motion during an earthquake is dependent on the composition and structure of the subsurface. Thick, water-saturated sediments are subject to several times more intensive motion than solid bedrock. For example, ground shaking measurements of San Francisco Bay muds are about ten times greater than those for nearby bedrock (Nichols and Buchanan-Banks, 1974). Intense ground motion could damage a pipeline's coating or significantly weaken its structural integrity. Ground motion can also induce sediment failures. Liquefaction of surface sediments can result in bearing capacity failures. Where liquefaction occurs in subsurface sediments, stiff clays on the surface can spread and move downslope. These lateral spreads can move as much as a mile (usually tens of feet) on slopes as low as one-half degree (Hoose, 1978). Subsurface liquefaction can also result in a subsidence of surface and subsurface sediments.

Where sediments are located on sloping terrain and sediment failures occur in surface or subsurface sediments, a mass movement of sediments downslope can occur. These large-scale movements include slumping, landsliding, debris flows and turbidity currents.

Slumping occurs principally in areas where there is significant slope and thick, unconsolidated sediments (such as at the edge of the shelf) and involves a simple downslope displacement along a plane of failure (a sediment layer along which movement occurs) with no significant deformation of the sediments' internal structure. Sediment slumps observed by sub-bottom profiling often resemble down-dropped blocks or folds. The failure planes are also sometimes visible on the profiles and resemble vertical faults with offset sediment layers on either side. There is a potential for renewed movement of the slumped sediments due to their instability.

Where movement continues past the slumping stage and the sediment mass begins to move along several failure planes, landsliding is the result. Compared to slumping, there is increased deformation of the internal sediment structure during landsliding.

As water is incorporated into a landslide and the slide is disturbed and remolded during movement, motion begins to occur along numerous failure planes and the slide begins to more closely resemble a "liquid" flow. The incorporation of water into the sediment reduces its strength and the resulting mass is very fluid. When observed on land the downslope flow is called a debris flow (e.g., mud flows in California). Although submarine debris flows have not been observed directly, the water available in the marine environment provides one of the conditions necessary for the formation of submarine debris flows (Hampton, 1972).

Turbidity currents are subaqueous suspensions of water and sediments that are sufficiently dense to flow downslope under the influence of gravity. It has been suggested that large turbidity currents may be generated as a distinct phase in the downslope movement of submarine debris flows (Hampton, 1972).

Areas most likely to be affected: The coastal geologic environments most often affected by seismically-induced ground failures include deltas, wetlands and lagoons. Portions of beach systems such as dunes, or the lee side of sand spits may also be susceptible when saturated (Hoose, 1978).

The slope of the terrain may also influence the type of seismic hazard that may occur. Steep terrain is subject to slumps, landslides, debris flows, and turbidity currents. Lateral spreads and associated ground cracking and bearing strength failures may occur on flat or gently sloping terrain (Hoose, 1978).

The edges of the continental shelf, the slope, and the heads of submarine canyons are extremely susceptible to sediment mass movements. These areas contain large deposits of unstable, unconsolidated sediments. Slumping has been reported in the vicinity of Lydonia Canyon at the edge of the North Atlantic OCS (Offshore Navigation, Inc., 1976) as well as along the mid-Atlantic shelf edge (Bennet et al., 1978). The existence of large, destructive turbidity currents on the shelf slope has been suggested. It is believed that a large earthquake on the Grand Banks in 1929 triggered a turbidity current that broke numerous communication cables in the vicinity. Velocities of this turbidity current have been estimated to be at least 22.7 feet per second (Emery et al., 1970).

Mass movements are also known to occur closer to shore. In the Gulf of Mexico, a landslide of deltaic sediments overturned one petroleum production platform and moved another three to four feet (Glaeser and Smith, 1977). The failure of some pipelines in the Gulf of Mexico has been attributed to slumping movement of deltaic sediments (Demars et al., 1977).

ENVIRONMENTAL DISTURBANCES

There are four major environmental disturbances caused by offshore pipeline installation: direct loss of bottom organisms from construction activity; turbidity effects; habitat alterations and alterations of physical and chemical characteristics of the construction area.

Loss of Organisms

The Problems: Organism loss along the pipeline route can be expected both where the pipeline is buried or unburied. Where the pipeline is placed directly on the ocean bottom, only those sessile and low mobility organisms on the sediment surface directly beneath the pipeline will be lost. Where the pipeline is buried, both nonmobile organisms and those living in the sediments will be removed.

Because of the relatively small area disturbed by pipeline installation, the number of organisms removed should not generally cause a large impact on the biological community. There are certain exceptions however, such as the loss of organisms, which are of special ecological or economic value. Therefore, during the route selection process, when considering the potential effects of organism loss along a prospective route, the most important concern is the type of organisms present, instead of the numbers or biomass of organisms lost.

Areas most susceptible to damage: Organism losses can result in major impacts in a number of areas. Although less extensive impacts can be expected in areas where offshore pipelines are not buried, offshore areas with economic resources, such as shellfish, lobsters or bottom fish (e.g., flounder), may be adversely impacted by pipeline installation. In addition, areas which contain small and/or unique habitats may be damaged if a relatively large percentage of a given population is removed. "Live bottom" areas--offshore areas associated with rock out-crops which have unusually high concentrations of invertebrates--and the "flower garden" coral reef areas off the Texas coast, are examples of these unique habitat types. Similarly, damage to rare or endangered species or their habitats would cause major impacts.

Nearshore and at the landfall, where trenching is likely and where more sensitive and vital habitats exist, the impacts from organism loss may be more severe. Impacts may be more extensive for a number of reasons. First, these coastal systems may be more fragile and, therefore, more susceptible to disruption and they may exhibit slower recovery rates. In addition, there is often a greater diversity of habitats in the coastal zone than in offshore areas, making each individual habitat smaller, and potentially more significant in coastal ecological processes.

Areas of particular concern when considering organism losses along a pipeline route include:

- coral reefs--which are generally located in latitudes 28° north to 28° south, and in waters less than 120 feet deep, with temperatures greater than 20° centigrade (Stern and Stickle, 1978);
- wetlands (marshes)--particularly when the wetland is small and/or is one of few or the only marsh in the estuarine system. The potential extent of marsh impacts is magnified because wetlands have slow recovery rates (up to 20 years may be required for complete restoration [Shanks, 1978]); and
- submerged grass beds--particularly in estuaries which have no shoreline marshes, because the grass beds then serve as primary nutrient sources and sediment stabilizing mechanisms (normally marsh functions) for the estuaries.

In addition, bottom areas used by fish for egglaying or inhabited by bottom dwelling larvae or juvenile forms may be adversely affected by bottom disturbances during those periods when spawning or hatching has recently occurred.

Turbidity Effects

The Problems: Significant turbidity effects will occur only when the pipeline is trenched. When pipelines are unburied, only very small localized elevations in turbidity will occur as the pipeline touches the bottom (particularly when the pipe is being laid in soft sediments). Increased suspended sediments from pipeline trenching may affect water column organisms and, in very shallow water where light penetration is sufficient to maintain them, bottom plants. When sediments resettle, bottom organisms may be smothered. The extent of damage will vary depending on the type of sediment disturbed (smaller sediment particles will remain suspended for longer periods of time), the amounts of sediment suspended, the flushing or mixing rate, and the types of organisms present in the affected area.

Water column organisms potentially affected by increased turbidity include phytoplankton and zooplankton (microscopic free-floating plants and animals) and eggs, larvae and adult forms of invertebrates and fish.

There is currently some debate about the effects of increased turbidity on phytoplankton photosynthetic rates. While laboratory studies have indicated a suppression in photosynthesis with increasing turbidity (due to decreased light penetration), field studies of dredging operations have generally shown no long-term decrease in photosynthetic rates resulting from increased turbidity levels. Researchers have speculated that interferences with photosynthesis resulting from increased suspended sediment concentrations and decreased light penetration, may be offset by increased suspended nutrients which stimulate photosynthesis (Morton, 1977).

Possible effects on zooplankton vary according to species sensitivity and suspended solids concentrations. In laboratory experiments, ingestion rates for two copepods (microscopic crustaceans) were reduced by suspended solids concentrations of 50 milligrams per liter (mg/l)* (Stern and Stickle, 1978). On the other hand, no obvious alterations in zooplankton species composition or density were reported associated with increased turbidity due to dredging operations in Chesapeake Bay (Goodwyn, 1970). It has been suggested that difficulties in sampling zooplankton may make accurate interpretation of field data difficult (Morton, 1977).

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* For comparison, average suspended solids concentrations in the Thames River, Connecticut estuary are as follows: average river concentration: 5 mg/l; storm concentration: 10-20 mg/l; at dredge site (while dredging with bucket dredge): 200-400 mg/l (Bohlen F., 1978: personal communication). Louisiana coastal waters have natural suspended solids concentrations of 50-100 mg/l (Degreenia,H.E.,1979: personal communication.)

Eggs and larval forms of invertebrates and fish are probably the organisms most sensitive to increased turbidity levels. It has been observed in laboratory experiments, however, that in a well-mixed environment, concentrations of suspended fine grained sediments up to 500 mg/l did not affect hatching success of four fish species--yellow perch, white perch, striped bass and alewife. Even though adult fish generally avoid areas of high turbidity, in one dredging experiment done in Mobile Bay, no damage to adult fish 25-50 yards from an active dredge was observed. (Stern and Stickle, 1978).

Resettlement of suspended solids may affect those benthic organisms which cannot move away from the area or which are incapable of reaching the surface after burial. For example, demersal (bottom) fish eggs may be buried. The symbiotic plant life associated with coral reefs may also be smothered. This is a particular problem when the sediments are anaerobic, causing suffocation (Morton, 1977). Most benthic organisms can, however, withstand high suspended solid concentrations for short periods of time (Saila et al., 1972). Bivalves, for example, generally exhibit no long-lasting effects from increased turbidity. While filtering rates decrease in turbid waters, when the animals are placed in clearer water, original filtering levels return (Stern and Stickle, 1978).

Areas most susceptible to damage: While increased turbidity will result from pipeline trenching, effects will generally be confined to a small area directly adjacent to the pipeline. Based on dredging experiments, few long-term or severe impacts are expected in most areas affected by high turbidities. There are, however, isolated situations and ecosystems which may be severely affected by increased turbidity and which should be considered during pipeline routing process. These areas of particular concern include:

- coral reefs--which may be damaged by resettling sediments;
- areas with very slow circulation and/or flushing rates--where the sediments will not be quickly diluted or removed (e.g., lagoons). Impacts may be further magnified in these areas if bottom sediments are made up of small grain size sediments which will remain suspended for longer periods of time; and

- spawning and nursery areas during season--eggs, larvae and juvenile forms are particularly sensitive to elevated suspended sediment levels. During spawning season when large populations congregate in small areas, even adult fish become more vulnerable to any type of environmental disturbance. Estuaries are prime areas for spawning and are, therefore, areas of particular concern.

In addition, pipeline-related turbidity increases may cause adverse effects in areas with naturally clear waters which may contain organisms less tolerant to turbidity increases than those living in naturally turbid waters.

Habitat Alteration

The Problems: Habitat alterations may be associated with both buried and unburied pipelines. Unburied pipelines are expected to cause little long-term alteration, and may, in fact, offer new habitat for colonizing species, similar to drilling platforms and other submerged surfaces which act as "artificial reefs." In general, trenching for pipeline burial disturbs bottom sediment structure which may alter the habitat characteristics of the area trenched.

In the marine environment, it appears that sediment structure and species composition and distribution are inter-related, although direct relationships are not always clear. Generally, filterfeeding bottom organisms (e.g., bivalves) are found in areas with sand and gravel bottoms, where strong currents keep the small food particles and organics in suspension. Deposit feeders (worms, etc.) are generally found in soft bottoms where sediments are more easily foraged (Morton, 1977). If trenching and resettlement results in temporary changes in sediment characteristics of one of these habitats, short-term changes in species composition may also occur. For example, if the hard bottoms which generally characterize spawning grounds are changed to soft bottoms during spawning season, spawning success may be adversely affected. In areas where extremely silty sediments are resuspended, soft shifting bottoms may result. Because this bottom type does not offer sufficient strength to support most types of bottom organism growth, the bottom is effectively "sterilized" (LaRoe, 1977).

At the landfall, pipeline installation may cause habitat alteration, particularly in wetlands where the "spongy" sediments are compacted when dredged to form pipeline installation canals. Where the canal is not refilled, two new habitats result - the open water system in the canal itself and the compacted sediment levees on either side. Even where filling is attempted, original sediment conditions may be impossible to duplicate (Conner, et al., 1976).

Areas most susceptible to damage: It is unlikely that sediment disturbances sufficient to cause widespread habitat alteration will result from most pipeline trenching operations in deep water. There are, however, certain areas which are particularly vulnerable to alteration and which may sustain long-term damage from changing habitat conditions. These areas of particular concern when considering potential pipeline routes include:

- wetlands--Habitat alteration is a frequent result of construction activity in wetlands. Wetland sediment conditions are very difficult to restore to their original state after construction has occurred. Frequently in place of original wetland sediment structure two new habitats are created - compacted sediment levees and open water canals;
- estuarine spawning areas--Particularly when the area is small or when it is the only area used by a particular species; and
- small or unique habitats.

Physical and Chemical Alterations

The Problems: There are three main concerns associated with physical and chemical alterations to an area from pipeline installation: changing an area's physical structure; altering circulation patterns; and changing chemical characteristics of the water column.

Changing the physical structure of an area is a particular problem at the landfall site. Altering dune structure by removal and later reconstruction may lessen the dune's capacity to protect upland areas behind it and may increase the rate of dune erosion (Rooney-Char and Ayres, 1978). Likewise, pipelines crossing barrier islands or beaches may affect their ability to protect the areas landward. In addition, the pipeline right-of-way might present a "weak link" (area of low resistance to physical stress) which could be breached during a storm (Rooney-Char and Ayres, 1978). Altering a wetland could change its hydrological drainage patterns (Longley, et al., 1978) and lessen its filtering and buffering capacities.

The potential for circulation changes from pipeline trenching is greatest in estuaries. If the trench is not completely refilled, a depression in the estuarine floor may result, offering an easier avenue for salt water intrusion into the estuary. Elevations in salinity further upstream in the estuary may affect spawning patterns and the distribution of estuarine organisms (LaRoe, 1977).

The composition of sediments resuspended by pipeline installation may affect the chemical constituents of the water column. Where sediments are severely contaminated with bacteria and organic material, localized decreases in dissolved oxygen levels may be expected (Morton, 1977). Sediments with high organic and nutrient content may also stimulate blue green algae ("nuisance") blooms (Morton, 1977). Whether or not toxic chemicals contained in sediments are released when resuspended is currently a topic of controversy. While some results seem to indicate that toxic materials are released when contaminated sediments are resuspended, other results contradict this conclusion (see Stern and Stickle, 1978 and Grimwood, et al., 1978).

Areas most susceptible to damage: Areas of particular concern when evaluating the potential for physical and chemical alterations resulting from pipeline installation include:

- dunes, barrier beaches and barrier islands;
- wetlands; and
- areas having polluted bottom sediments.

SECTION 4

ASSESSING THE FISHING PROBLEMS

There are a number of concerns to fishermen regarding potential interferences between fishing and offshore petroleum activity. There are two particular issues related to pipelines:

- loss of fishing area along a pipeline route and its associated rights-of-way; and
- bottom obstructions which may cause fishing gear damage or loss. These obstructions include: the pipeline itself when laid directly on the ocean floor, whether exposed or covered with stone, concrete or some other protective coating; buried pipelines which become re-exposed by waves or currents; rocks, clay, etc. exposed during pipeline trenching; and the bottom debris present along the pipeline route.

This chapter discusses those pipeline/fishing interferences, highlighting experiences and experimental results obtained in the North Sea petroleum development area.

LOSS OF AREA

Loss of fishing area to production platforms and pipelines is a concern to fishermen both in U.S. frontier areas, (particularly the Georges Bank and mid-Atlantic areas which support large fishing industries) and in the North Sea. A University of Aberdeen report, commissioned by the British Fishing Federation and the Scottish Fishermen's Federation, entitled "A Physical and Economic Evaluation of Loss of Access to Fishing Grounds Due to Oil and Gas Installations in the North Sea" examines this fishing access problem as it pertains to North Sea development areas (Department of Political Economy, 1978). (In addition to area lost to pipelines and rights-of-way, other oil and gas related installations, including rigs and platforms, subsea completions and suspended wellheads [wells which have been drilled and capped pending further development] are also discussed in the report.)

This report estimated the range of area lost to fishing activity due to pipeline installations based on two sets of assumptions. First, two pipeline corridor widths were assumed as "safety zones" i.e., areas avoided by bottom trawling activity: 100 meters (328 feet) and 500 meters (1,640 feet). Secondly, assumptions were made regarding the proportion of the total pipeline corridor actually removed from bottom fishing activity. Two values were chosen: 20% and 100%. Thus, four scenarios were generated, from least area removed (20% of a 100 meter wide pipeline corridor) to most area removed (100% of a 500 meter wide corridor).

Estimates ranged from 30.86 square miles to 771.8 square miles lost in the middle and North Sea (above 55°N latitude) to fishing activity as a result of the existing pipeline network (consisting of approximately 1,235 miles of pipeline) (Department of Political Economy, 1978). Southern North Sea (south of 55°N latitude) loss estimates ranged from 9 square miles to 226 square miles (Department of Political Economy, 1978).*

Fish catch losses due to loss of fishing area access were then estimated. Two methods of estimating losses were employed and yielded a range of 66 tons to 1,786 tons of demersal (bottom) fish lost in the North and middle North Sea for the year 1976 (Department of Political Economy, 1978).

The authors acknowledged, however, that numerous problems were associated with this type of analysis, particularly the catch loss estimates (Dept. of Political Economy, 1978). This was due in large part to the fact that, by nature, the amount and accuracy of fish catch data is limited, making it difficult to draw conclusions based strictly on statistical analysis of the information. In addition, it was difficult to determine appropriate statistical methods for estimating catch loss.

Nevertheless, the study points out even if quantitative loss estimates are disregarded, qualitative analysis would seem to infer that pipeline installation may result in loss of access along the route. For example, although pipeline burial at sufficient depths should eliminate the risks of trawling interference, past experience has shown that pipelines can and have become reexposed. Because of the potential for gear damage or loss and associated loss of fishing time and revenue should trawl equipment become hooked, it would be understandable if the fishermen chose to avoid both unburied and buried pipeline routes, and large areas surrounding them (Dept. of Political Economy, 1978). There is also the inference of "better safe than sorry" in the reported request of oil companies, asking fishermen to "give pipelines a wide berth in their operations" (Dept. of Political Economy, 1978).

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*Similar estimates are presented in Olsen's (1977) paper in Volume II of the New England Regional Commission Report, "Fishing and Petroleum Interactions on Georges Bank." Two "safety zones" are assumed - 1,650 feet (500 m) and 300 feet (91.44m). Estimated area lost to fishing ranged from 73 to 364 acres per mile. Applying these "loss per mile" figures to the 1,235 mile Northern North Sea pipeline network results in estimated losses of 135.85 square miles to 691.6 square miles.

An additional concern is the placement of gathering lines to connect petroleum platforms. These pipelines often form triangular patterns which may result in total loss of fishing access inside the boundaries inscribed by the platforms and the connecting pipelines (NERBC, 1979).

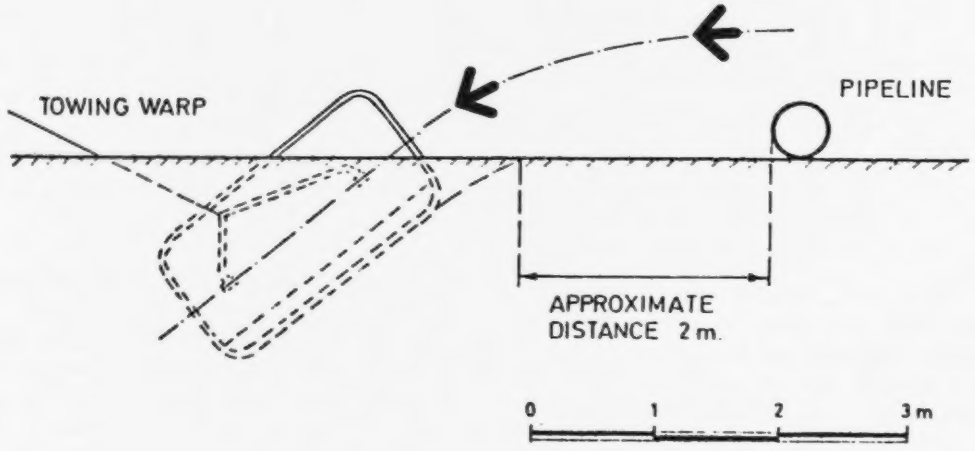
Regarding loss of fishing access due to pipeline installation in the North Sea, the Aberdeen Study concludes: "Regardless of the evaluation of the overall results we have presented for the North Sea, there is no doubt that some fishermen have suffered losses. It is not really the Scottish or British fishing industry as a whole which is affected, but rather particular fishermen and fishing fleets in geographic areas." (Dept. of Political Economy, 1978).

Recently, one of the authors of the University of Aberdeen study, offered these additional observations on the numerical estimates of area lost. Overall, the estimated physical area lost to fishermen due to structures related to offshore oil and gas activity (including pipelines, platforms, exploratory rigs and suspended wellheads) ranged from 190 to 830 square nautical miles (253 to 1104 square miles) for the whole North Sea. This area amounted to between 0.3% and 1.2% of the total fishing area available (MacKay, 1979). Pipelines, which account for 17% of the lower case and 77% of the upper case estimates, would thus be "responsible" for area losses of between 0.02% and 0.92% of the total available fishing area in the North Sea. The results were summarized as follows: "I think that it would be fair to conclude that the statistical analysis is inconclusive. In no case is there firm evidence to show a decline in catches following the installation of exploration rigs, platforms, pipelines, etc. On the other hand, there is no firm evidence to show the opposite, and the statistical problems with the catch data are such that it is unlikely that any conclusion will be reached." (MacKay, 1979).

TRAWL GEAR DAMAGE

Although it is generally believed that bottom trawl gear will not cause extensive damage to pipelines (see FLAGS Study results reported in Section 2), damage to trawl gear is also a concern. As part of the Shell-Expro FLAGS Study, VHL River and Harbour Laboratory at the Norwegian Institute of Technology at Trondheim, Norway ran a series of experiments to examine this problem. The following results were reported by Carstens (1977).

Three types of otter trawl boards were utilized in a series of laboratory and field tests designed to examine how trawl equipment responded to impact on pipelines. Laboratory results indicated hooking of gear on the pipeline did not occur when the pipeline was struck by a board in a normal upright position. Instead, the board passed over the pipeline and resumed its previous upright state. This occurred regardless of whether the pipeline rested on the bottom, was spanned, or was lying in a trench. However, when the trawl door was significantly tipped, hooking lasted up to a few seconds, during which the tow warp (rope) was stretched elastically. Upon release, the tow warp force was sufficient to accelerate the board to a high velocity; at times the board even "took flight" for a few meters. This is illustrated in Figure 12.



Source: Carstens, 1977, p.24.

FIGURE 12. TRAWL GEAR HOOKING AND RELEASE.

Field experiments showed similar results to those obtained in the laboratory. Hooking occurred three times when the otter board struck the pipeline at an angle of less than 45°. Tension was sufficient to break the warp twice; the third time the towing vessel was proceeding slowly and was brought to a complete stop.

Measured warp loads placed on the board tow lines increased from three to five times the normal tension during board pullover. This increased tension was observed with both untrenched and spanned lines. Trenched, but unburied, lines offered even more resistance to trawl board pullover (Broussard, et al.,1978). Table 3 presents calculated pullover loads placed on the three trawl door types.

TABLE 3. PULLOVER LOADS ON TRAWL DOORS

	Weight (kg)	Maximum Pullover Loads (tonnes force)	
		Untrenched	Trenched
V door	1500	11	22
Oval door	2000	10	15
Rectangular door	2000	15	17

Source: Shell Expro, 1977, p.43.

The following conclusions were drawn from these experiments. First, if a trawl door hooks briefly on a pipeline but then quickly unhooks, no trawl door damage is likely. On the other hand, there is a remote chance that a trawl door will hook but not unhook. A number of unusual conditions are required to cause this event. To hook the pipeline, an otter trawl door must be lying flat upon impact with the pipeline or must catch under a spanned pipeline with a small bottom clearance. The trawl door may not unhook if conditions prohibit deflection of the door or where the door becomes imbedded in very stiff bottom materials (Carstens, 1977). If the board hooks and holds fast and the tow warp breaks, besides losing the door, the warp will snap, possibly injuring crew on the ship's deck.

BOTTOM DEBRIS

There are three major types of bottom debris associated with offshore pipeline routes: bottom materials dug up in the trenching process; stone which may be used to cover a pipeline; and debris from pipelaying operations and passing vessels. Objects encountered by North Sea fishermen have ranged from oil drums and scrap metal to steel cable, pipe turnings and heavy machinery dumped overboard rather than repaired (NERBC, 1979). Claims for gear losses caused by bottom debris in the North Sea appear to have averaged approximately two per week in 1976 and 1977 (Dept. of Political Economy, 1978).

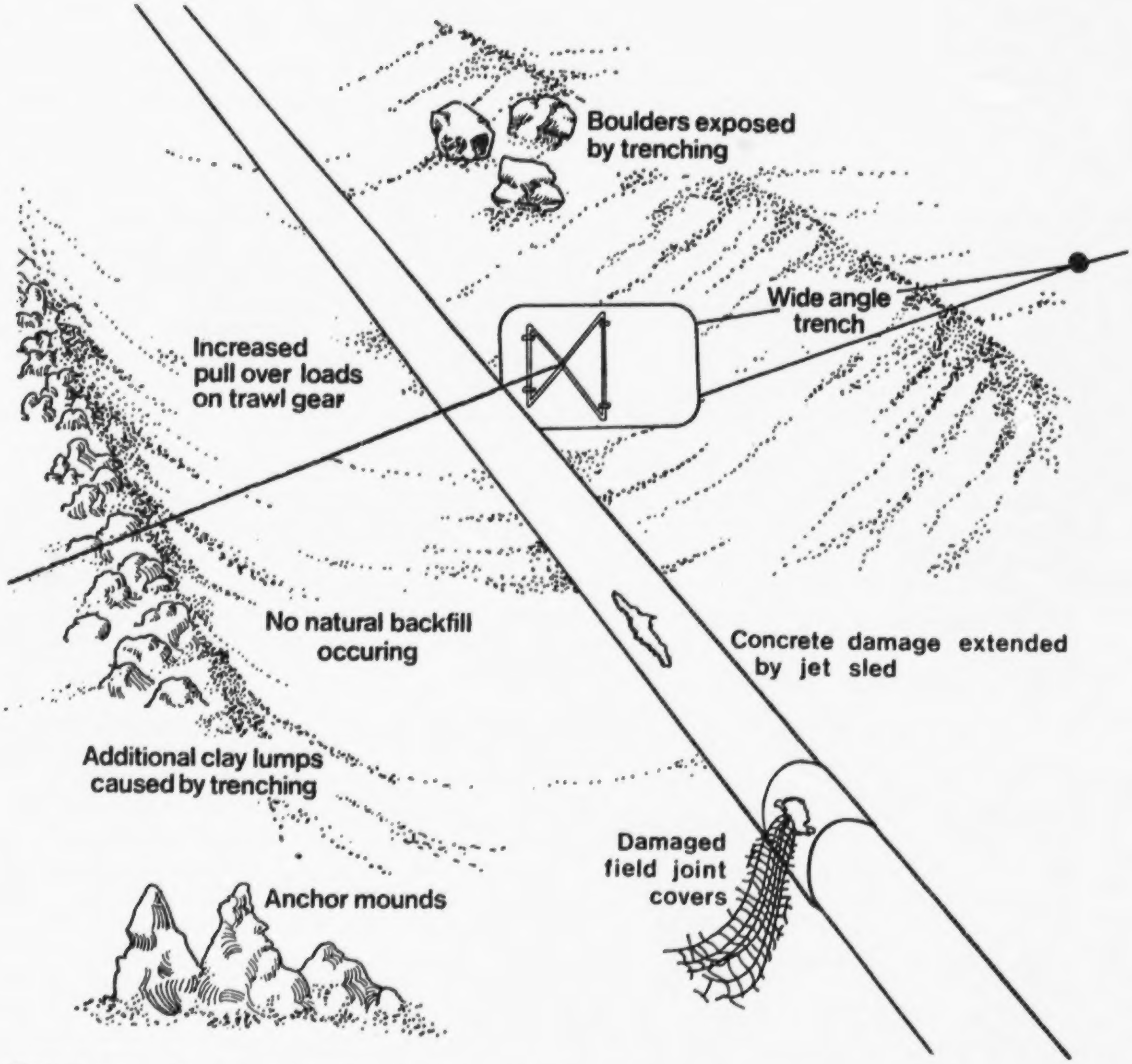
Trenching operations often expose rocks and result in mounds of sediment on either side of the trench which may catch the nets of passing trawl gear. Damage may also result when nets are caught on damaged areas of a pipeline's concrete coating. Figure 13 summarizes various fishing gear problems associated with trenched offshore pipelines.

Crushed stone has been considered for use in protecting pipelines in North Sea areas where natural backfilling has not or is not expected to occur. For example, artificial burial of portions of the Ekofisk to Emden pipeline was suggested after it was discovered that much of the pipeline had not been buried naturally (NERBC, 1979). However, North Sea fishermen have reported that the crushed stone fill gathers in their nets, where it wears holes, releasing both the fish and stone. This results in damaged gear and loss of catch (NERBC, 1979).

Triggered in part by complaints received from fishermen, Norwegian authorities requested that all license holders on the Norwegian Continental Shelf perform debris surveys in all areas affected by oil and gas activities including all pipeline routes, abandoned well sites, and platform installations. In response to this request, the Norpipe pipeline routes from Ekofisk to Teesside (oil) and Ekofisk to Emden (gas) were surveyed, and subsequent clean-up operations undertaken.

Survey work began using side scan sonar and submersible vessels to locate and identify potential debris "targets" within a 100 meter wide corridor along the pipeline route. Targets were then visually examined using a submersible and classified as rubbish or debris. Rubbish was defined as "minor or small objects considered to be unable to damage or hinder trawl nets or endanger divers or the pipe itself" (Kjolseth, 1978) and included such objects as empty oil drums, boxes, tires, ropes, fishing nets, etc. These targets were not retrieved. Debris was classified as "any objects considered able to damage or hinder trawl nets or endanger divers or the pipe itself" (Kjolseth, 1978) and included: steel pulley blocks, plates or pipe, machinery parts, etc. Buoys and electronic "pingers" were attached to these debris targets, which were later retrieved.

The Emden gasline survey lasted from July 26 to October 7, 1977, during which time over 50 debris articles along the approximately 250 mile route were identified and retrieved. The Ekofisk to Teesside oil pipeline survey took place from October 7 to December 11, 1977, when work was stopped due to bad weather. Work was completed in 1978. Estimated costs to Norpipe for the 1977 portion of the debris survey and retrieval were approximately $4 million (NERBC, 1979).


Boulders exposed by trenching
Wide angle trench
Increased pull over loads on trawl gear
No natural backfill occuring
Concrete damage extended by jet sled
Additional clay lumps caused by trenching
Damaged field joint covers
Anchor mounds

Source: Shell Expro, 1977, p.47

FIGURE 13. DEEP WATER TRENCHING PROBLEMS.

SECTION 5

SOLVING THE PROBLEMS--CHOOSING A PIPELINE ROUTE

The process of selecting a final pipeline route from offshore platforms to the shoreline involves analysis of the technological feasibility of installation and the geological and environmental characteristics of the route. This chapter discusses this final siting process, including:

- general industrial siting criteria to use in analyzing route feasibility;
- areas to avoid in pipeline siting, including geologically unstable and environmentally sensitive areas; and
- mitigation methods for minimizing unavoidable impacts, both to the environment and to the other users of the area.

TECHNICAL SITING CRITERIA

The technical feasibility of installing a proposed pipeline can be determined by using criteria based on what the pipeline industry considers the most and least desirable features of a pipeline route. (Appendix B contains a complete description of industry's route selection procedures.) Some of these considerations are presented in Table 4. Positive and negative aspects of offshore and coastal areas and potential conflicts with other coastal uses are shown. Although this table describes "least preferred" areas, it is possible for pipelines to be installed in a number of these adverse situations, as illustrated by North Sea experiences where, for example, cable crossings and bedrock sea bottoms have not prevented pipeline installation (NERBC, 1979).

Table 5 presents technical criteria for screening potential pipeline routes and landfalls developed by a consortium of gas pipeline companies as part of a survey of sites along the British coast. This survey was undertaken in anticipation of discoveries of additional offshore gas fields. Similar to the U.S. industry considerations in the previous table, these criteria, when taken together, represent an ideal routing situation; "real world" routes have often included many undesirable features, because

TABLE 4. INDUSTRIAL PIPELINE SITING CONSIDERATIONS

Considerations	Most Preferred Features	Least Preferred Features
COASTAL WATERS		
Submarine Topography	Level or gradually sloping grade, relatively stable contour	Continual, drastic up and down grade changes, dynamic contour
Submarine Sediment	Easily removed light sediments (sand or sandy loam), horizontal homogeneity over line length, stable sediments over full range of local current velocities	Heavy sediments, not easily removed, which require loosening before removal (mud, clay gravel and rock), continual changes in sediment composition over line length, dynamic sediments within range of local current velocities
Submarine Sand Waves	No presence or historical presence	History of formation and presence
SHORELINE		
Shoreline Sediments	Homogeneous (non-layered), stable high bearing strength, low water table, non-"runny" soils	Diverse texture layers, unstable low bearing strength, high water table, "runny" wet soils
Barrier Islands	Sandy ocean front, relative historical stability, little wetland or bay area landward of shore crossing	Heavy sediment ocean front, significant historical migration and tidal inlet formation, large wetland or bay expanse between island and mainland
Beaches	Accreting, sandy beach with historical stability (long-term and during storm activity)	Eroding, heavy sediment ocean front with a history of significant normal and storm-induced erosion
Onshore Sand Dunes	Small in size with historical erosion levels small in magnitude	Large in size with historical erosion levels large in magnitude

TABLE 4.

Considerations	Most Preferred Features	Least Preferred Features
Wetlands	Firm soil conditions (high trafficability) with no obstructions such as tree stumps	Soft, muck soil conditions, (low trafficability) with many obstructions which are hard to remove
Bluffs	Small in size with a history of relative stability and no history as a run-off area	Large in size, with a history of erosion and recession from the water's edge, and a known run off point for upland storm, flood and waste waters
SPECIAL COASTAL USES		
Commercial Fishing Areas	Areas in which no bottom-disruptive fishing techniques are employed or foreseen to be, and areas which are not controlled by private lease, license or the like	Areas in which dredges, bottom trawling, tongs, and the like are used in harvesting fishery products, areas that are privately leased or granted
Wrecks	Areas which contain no wreckage	Areas which have wrecks requiring circumvention
Ship Channels and Anchorages	No major or minor channels which require periodic redredging of the route, no anchorage area harboring large commercial vessels in the route	Periodically dredged channels; commercially utilized heavy anchorage areas
Areas of Unexploded Ordnance	No designated explosives dumping grounds or live ammunition practice firing areas in the area, no record of accidental ordnance release	Nearby areas of past unexploded ordnance disposal or live ammunition practice firing areas; records indicating possible presence of accidentally released live ordnance
Recreational Areas	Little or no recreational uses	Frequent, highly used for recreation

TABLE 4. (Concluded)

Considerations	Most Preferred Features	Least Preferred Features
OTHER SPECIAL USES		
Buoy Testing Areas	No buoy testing area to be traversed	One or more buoy testing areas to be traversed
Areas of Surface and Bottom Activity Restrictions	No areas of activity restriction to be traversed	One or more areas of activity restriction to be traversed
Prohibited Areas	No prohibited areas to be traversed	One or more prohibited areas to be traversed
Cable Areas	No cable areas to be traversed	One or more cable areas to be traversed
RIGHTS-OF-WAY	Pre-existing or easy to obtain, inexpensive and not likely to generate public opposition	"Frontier" area, devoid of existing utility rights-of-way, hard to obtain, expensive and likely to generate public opposition

Source: after Rooney-Char and Ayres, 1978, p.104-106.

TABLE 5.

PHYSICAL CONSTRAINTS ON PIPELINE LANDFALLS

CRITERIA FOR EVALUATION

Onshore (above limit of marine activity)

1. 500 acres land with slope under five percent; well drained; average bearing capacity.
2. within one mile of coast; or
3. two sites with similar physical characteristics: one 50 acres within one mile of coast, one 500 acres within five-ten miles of the coast.

Coastal (from low water mark to upper limit of marine activity)

1. less than ten percent slope.
2. sediment at least three meters.
3. absence of unstable/very mobile sediments.
4. absence of hard untrenchable rock outcrops.
5. absence of high velocity currents.
6. absence of rock cliffs (ten meter high soft sediment cliffs permissable).
7. absence of unstable sand dunes.
8. space for landing two pipelines (100-200 meters).

Offshore (low water mark to depth of 100 feet)

1. less than ten percent slope, low to moderate undulation.
2. sediments at least two meters deep.
3. absence of mobile seabed sediments, especially sand waves.
4. absence of high velocity currents.
5. absence of untrenchable rock.
6. absence of deep trenches; other major seabed irregularities.
7. absence of minor seabed irregularities.

Source: NERBC, 1979, p.36.

other considerations (such as economic factors) have outweighed the technical difficulties in construction (NERBC, 1979).

PRECONSTRUCTION PLANNING

In addition to studies examining the technical feasibility of installing a pipeline along a proposed route, it is important to identify those areas which should be avoided because of geologic instability or environmental sensitivity. Preconstruction planning should also include consideration of potential interferences with fishing activity along the route.

Geological Hazard Areas to Avoid

When industry considers a potential pipeline route, the siting criteria are based to a large extent on a geologic analysis of the area. Generally, geologic hazard areas are those containing the "least preferred features" (see Table 4) along the route and include:

- areas with adverse sediment conditions--This includes soft, unconsolidated fine sediments that provide poor foundation characteristics or could form a fluid backfill in a pipeline trench. Sediments prone to liquefaction or other bearing strength failures should also be avoided;
- areas subject to scour--These are areas with swift bottom currents or intense wave activity with sediments that are mobile under those current velocity conditions;
- sand waves--These large, mobile features may present a physical barrier to construction or expose a buried pipeline and subject it to possible spanning;
- eroding shorelines--Shorelines that have a past history of significant erosion should be avoided;
- active faults--Active faults (those that have disturbed recent sediments or have been the location of recent earthquakes) should be avoided in pipeline routing;
- deltas--Deltas have large quantities of rapidly deposited, cohesionless sediments. Their unstable sediment structure makes them susceptible to sediment bearing strength failures. The seaward edges of many deltas are the locations of sediment mass movements. A high organic content within the sediments allows the formation of gases that further weaken the sediment structure.

- heads of submarine canyons--These are sites of sediment mass movements and have an irregular distribution of erosional and depositional areas resulting in considerable bottom instability (Glaeser and Smith, 1977);
- slump areas--Areas with detachment of masses of sediments near canyon heads and along the edges of continental shelves or deltas should be avoided; and
- buried channels and valleys--Sediments filling buried valleys and channels are generally unconsolidated and in places have slump features that indicate instability (Glaeser and Smith, 1977). The unconsolidated sediment fill has variable foundation characteristics and may be prone to bearing strength failures.

Environmental Areas to Avoid

Because of the relatively small amount of disturbance and the short time period involved, it appears that in general, only small-scale, localized environmental damage will result from pipeline installation activities. However, there are particularly sensitive environmental areas which may be easily disrupted by pipeline installation (particularly trenching operations) and which may take long periods of time to recover. Where possible, these types of systems should be avoided in pipeline routing. These "avoidance areas" include:

- wetlands--Wetlands serve many vital coastal functions including: acting as a transitional zone between fresh and salt water; filtering out land-derived pollutants from runoff; providing food supplies (decomposed marsh vegetation) to adjacent coastal zone communities; and serving as spawning and nursery grounds for coastal fish and nesting and migratory resting areas for birds. Because of their unique structure, wetlands, once altered, are very difficult to restore to their original nature. Because of their ecological importance in coastal zone dynamics, and the difficulty in their restoration, wetlands should be avoided, whenever practicable, in pipeline routing;
- spawning and nursery areas--These areas include both offshore and nearshore (particularly estuarine) areas. Construction may be particularly damaging where trenching occurs and in areas used for demersal (bottom dwelling) spawning or larval growth. If routing through these areas is unavoidable, construction should be scheduled to avoid spawning and nursery seasons;

- barrier beaches and islands--Particularly those with a history of erosion;
- unique habitats--These include areas of particular ecological significance such as coral reefs, coastal ponds and "flower gardens;"
- rare or endangered species habitats; and
- small habitats--These include areas where the area disturbed by installation makes up a large percentage of the total habitat, or where high concentrations of organisms exist in small areas. These habitats include: seagrass beds; kelp beds; and (where applicable) shellfish beds.

In addition, where possible, it may be advisable to avoid areas with extremely polluted bottom sediment conditions.

Preconstruction Studies

To locate "avoidance areas" and to determine geological and ecological acceptability, preconstruction studies of a proposed pipeline route may be necessary.* Existing information may provide much of the necessary data for route assessment. For example, information on geological and ecological characteristics of an offshore route may be obtained from:

- lease sale environmental impact statements--These assessments contain general geological and biological data and may include maps of surface sediments, currents, etc.;
- data records--From universities, research centers and oceanographic institutes which may have ongoing research projects in offshore areas under consideration for pipeline routing. (National Oceanographic and Atmospheric Administration [NOAA] - Sea Grant funded institutions may be prime information sources);
- federal agencies--Including NOAA and U.S. Geological Survey (USGS) for geological, physical and chemical oceanographic information; National Marine Fisheries Service (NMFS) for fisheries data; and U.S. Fish and Wildlife Service for selected coastal ecosystem characterizations; and
- state agencies--Including Coastal Zone Management and other natural resource planning agencies which may have detailed data and maps of state shoreline

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*It has been suggested that due to regulatory requirements (e.g. Environmental Impact Statements) preconstruction studies would be necessary prior to pipeline installation. Hock, J. (Dept. of Energy) 1979: personal communication.

and nearshore systems and selected natural resource areas, e.g., wetlands.

In addition, pipeline companies may have gathered much site-specific information (particularly geological) on a proposed pipeline route.

In some cases, however, data may be insufficient and field and/or laboratory studies may be necessary. The following are elements of a full-scale geological and ecological characterization of a potential route. (This complete baseline information-gathering study would be modified to address the information needs of a particular routing proposal.) A complete geological profile of an area would include the following types of data:

- _bottom currents_--Using continuous recording current meters;
- _bottom and sub-bottom profiling_--Using fathometers to determine water depth and seismic profiling (mapping) to determine sediment configurations and identify shallow subsurface hazards (faults, shallow deposits of natural gas, etc.);
- _bottom obstacle detection_--Using side scan sonar to detect bottom obstacles such as wrecks, rock outcrops and sand waves;
- _sediment sampling_--Using bottom coring devices to determine sediment type, strength and depth. In addition, laboratory tests may be conducted on collected samples to determine sediment strength and susceptibility to liquefaction; and
- _seismicity_--Using ocean bottom seismometers along the proposed route(s).

A complete ecological baseline data gathering study would include:

- _ecosystems characterization_--Identifying plant and animal species, number, and distribution, based on periodic samples taken at predetermined locations to ensure data comparability. (Laboratory studies on construction effects [e.g., increased turbidity] on native species may be desirable); and
- _literature reviews_--Reviewing literature for results of previous experiments in which the same species, the same area or conditions similar to those expected from pipeline disturbance have been examined. Both field and laboratory results should be considered.

Pipeline/Fishing Interferences

Potential pipeline/fishing interferences may be minimized by frequent consultation with fishermen on routing alternatives prior to final route selection. In addition, prior to construction, an important technical consideration will be whether or not to trench the pipeline in active bottom fishing areas.

Trenching: Originally, offshore pipelines were required to be trenched because it was thought that the trenching (and expected natural burial) would protect the pipeline from damage caused by hurricanes and other natural forces. However, experiments have shown that protection is not afforded in offshore areas where natural burial does not occur, leaving the pipeline trenched but exposed. Experimental results indicated that concrete coating alone offered adequate protection from trawl gear damage. Raising and lowering trenching machines over a pipeline may, in fact, cause damage to concrete coating, thus lessening its protection ability. In addition, trenched but unburied pipelines actually posed a greater threat to bottom trawl equipment than pipelines laying directly on the ocean floor. (See pages 26 through 30 and 60 through 62 for a detailed description of these experiments and results.) Therefore, it would appear that in certain offshore segments of pipeline routes--in particular, where burial is not expected to occur (e.g., in areas of low bottom current velocity) and where concrete coating alone is thought to provide sufficient stability and protection--trenching may not be necessary or advisable.

Consultation: Consultation with fishermen using offshore fishing grounds which may be traversed by a pipeline is the best way of minimizing potential fishing/pipeline conflicts. In the North Sea, various consultation methods are currently in use, including both formal governmental channels of discussion and informal coordinating efforts between fishermen and oil companies. For example, final routing of the FLAGS gasline included numerous consultations with fishermen's organizations because the originally proposed route crossed several prime fishing areas. The fishermen suggested an alternate route, avoiding the grounds. A compromise route was chosen, which skirted the edges of the grounds. The fishermen, however, then requested that a route very similar to the original be used because it was the edges, rather than the center of the grounds which they preferred to fish (NERBC, 1979).

Consultation with fishermen may also provide the benefit of fishermen's knowledge of the pipeline routing area. This was shown to be the case in routing the Frigg gasline when local fishermen provided information on an offshore rock formation (Rattray Rocks) which was then avoided in pipeline siting (NERBC, 1979).

INSTALLATION TECHNIQUES

Using appropriate construction and restoration techniques can further minimize damage along a chosen pipeline route. There are a number of general techniques which can be used in various ecosystems, and others that are particularly applicable to specific landfall types.

General Installation Methods

The following techniques may be used along the entire length of a pipeline route to minimize the disturbance related to pipeline construction. Although it is recognized that it may not be possible to use these methods in every case, they should be considered for use wherever possible.

Scheduling: Pipeline installation should be scheduled to minimize adverse environmental impacts where practicable. Construction during fish and bird migration and during mating seasons should be avoided wherever possible. In addition, scheduling during periods of lowest biological productivity may also be considered to minimize impacts. Lowest productivity, however, generally occurs during the winter months - the most hazardous time for pipelaying operations. Construction time should be limited to the shortest time required and restoration of the disturbed area (particularly at the landfall) should occur as soon as possible.

Construction Methods: In areas with loose, cohesionless sediments where high turbidity is expected, silt curtains (polyethylene sheets used to trap suspended sediments) may be used. (These devices are only effective in areas with very slow water movement.) Where sediments are heavily polluted, hydraulic dredges may be considered instead of conventional trench digging machines. If a dredge is used, polluted spoils from the trench may be removed from the site and the trench refilled with clean backfill material. Two major difficulties are associated with the dredging method: appropriate disposal of the polluted dredge spoils and acquisition of suitable clean backfill. In addition, this method could prove quite costly.

Restoration: The disturbed area (particularly at landfall area) should be restored as quickly and as close to original conditions as possible. Original substrates and native species should be used wherever feasible. Where pipelines traverse fishing grounds, routes should be placed on appropriate navigation charts and fishermen notified of the new pipeline installation.

Debris: Disposal of debris offshore in U.S. waters is currently regulated by various acts including the Ocean Dumping Act of 1972, and by OCS lease stipulations and operating orders.

Recent passage of ocean dumping legislation may also help to reduce debris problems in the North Sea. To ensure that no debris is disposed of along future North Sea pipelines, Norpipe and Phillips have drafted a clause pertaining to debris disposal at sea which will be included in their contract stipulations with pipeline installation contractors. The clause states that:

> During the work, Contractor shall not dispose of any material into the sea or air, which can be of danger to or interfere with other marine activity or life. The seafloor, sea, or air shall not be contaminated. As soon as the work is completed, the seabed shall, if practical, be brought back to original condition and Contractor shall clear the premises of debris, waste material, and equipment remaining from the work. Nothing shall be left which can interfere with fishing, marine, or other activity. All material belonging to Company shall be loaded for storage or to a location as directed by the Company Representative. Contractor shall be responsible for the recovery of any debris it dumps and shall bear the cost of such recovery operations. (NERBC, 1979, p.57)

Landfall Installation Methods

Wetlands: Because of their unique coastal value and structure, wetlands disturbance should be minimized. The following construction and restoration techniques should be considered for use whenever possible:

- crossings--Wetlands should be crossed at their narrowest point;
- pipeline installation--Pipelines should be trenched and buried. Because it disturbs less area, the pull technique would be preferable to the flotation method. In addition, wherever practicable, the "double ditching" construction technique should be used. In this technique, topsoil and underlying soil are removed separately and stored on opposite sides of the trench. When the trench is refilled, underlying soil, then topsoil are replaced in the trench. Plugs may be placed at intersections of pipeline trenches and natural waterways to prevent interferences with natural drainage (Longley et al. 1978). Refilling trenches should occur as soon as possible. If additional clean fill is required to restore original topography (in the event that original sediments have settled and compacted), it should be placed in the trench first, followed by underlying sediments, then topsoil; and

- restoration--Affected areas should be restored as soon as possible with native vegetation. Use of plants from adjoining wetlands may be considered to foster quicker regrowth. If construction occurred in late summer or fall, another planting the following spring may be desirable to allow a full growing season prior to fall migratory bird feeding.

The following methods may be used to control alterations in marsh circulation patterns:

- subsurface waters--Impervious materials (such as clay) may be placed around the pipeline if ground water protection is necessary;
- surface circulation--Where pipeline installation canals cannot be refilled, plugs should be installed at intersections with natural streams to prevent mixing and drainage alterations. Plugs should be designed to withstand any likely disturbance for the life of the pipeline. Wherever possible, surface drainage patterns should be restored to preconstruction conditions when pipeline installation is completed; and
- pipeline elevation--In cases where no other alternative will maintain original water circulation patterns, elevating the pipeline on pilings may be considered. However, above ground elevation may expose the pipeline to much greater risk of damage than if the pipeline were buried.

Beaches: While accreting beaches are likely to suffer only short-term and small-scale damage from pipeline installation, severely eroding beaches and dune structures may suffer greater damage from construction activity. In naturally eroding shoreline areas, pipelines should be buried below the projected depth of sediment removal by erosion. In some cases, artificial nourishment (periodic placement of compatible sediments on the beach landfall) may also be considered to provide additional pipeline protection. In other cases, it may be necessary to use sediment trapping structures such as groins, jetties, and breakwaters to artificially build up a pipeline landfall. While these accretion structures will help stabilize the landfall, they may result in erosion downdrift of the accretion structure. The following techniques may be considered to minimize these downdrift effects:

- initial beach fill--Filling the landfall area with additional sand to supplement sediment provided by longshore drift; and

- sediment pumping--Pumping sediments updrift of the accretion structure into downdrift waters, thus reintroducing them into the longshore drift process.

In areas where pipelines must be placed through dunes, the following techniques may be considered to minimize installation effects:

- construction--While trenches are open, they may be sprayed with substances such as crelawn bitumen, a tarlike material, to minimize slumping and dune erosion (Walton and Ritchie, 1975). Equipment movement should be limited to specific routes to protect areas adjacent to construction sites;
- sand storage--Trenching requires the removal of large quantities of sand which need to be stored until replaced in the trench. The upper layer of sand and vegetation and the remainder of the dune should be removed and stored separately in areas protected from wind erosion and disturbance by construction machinery. While land directly behind the dune line would provide this protection, the vegetation in this area is fragile and would likely be destroyed by storage. Therefore, other storage sites may be preferred. Erosion of stored sand may be prevented by watering the storage area, covering it with protective material (such as clay-rich soil), spraying it with erosion prevention substances, and employing erosion control structures such as snow fences; and
- restoration--After pipelaying and artificial burial is complete, dunes should be restored to their original height and slope so that normal beach-dune sediment exchange can resume. The top layer of sand should be placed on the dune's surface and replanted with native vegetation. (Annual spring plantings of mature vegetation may be necessary to ensure completely successful restoration.) Because dunes are particularly vulnerable to wind and wave erosion until they are restabilized, snowfences, brush, and where erosion may be particularly severe, stabilization structures, may be used to protect the dunes until the natural restabilizing process is completed.

OPERATIONAL PROCEDURES

Various techniques may be used to ensure safe and efficient operation of a pipeline system after installation. These include: notifying other users in the area of the pipeline's location; and inspecting the pipeline at periodic intervals.

Recording Route Location

Once installed, pipeline route locations should be adequately identified to minimize the risks of interference with other offshore activities. Possible methods of notification include publishing the route's location in "Notice to Mariners" and placement of the route on appropriate nautical charts. If necessary at the landfall, the pipeline's route may be delineated with appropriate markers.

Pipeline Inspection

Pipeline inspection programs are designed to ensure the proper installation and safe and efficient operation of a pipeline system. In the U.S., pipeline inspection programs are administered by the Office of Pipeline Safety - U.S. Department of Transportation. There is also a Memorandum of Understanding between the Department of Interior and the Department of Transportation which provides for coordination between the two departments in their OCS pipeline inspection activities. Current regulations require only that surface waters over an underwater pipeline be checked by the operator at least every two weeks to observe any indications of leaks. Additionally, those pipelines utilizing cathodic protection require a yearly test of the protection system to determine if it meets federal requirements. The pipeline construction industry also has self-imposed inspection programs which may involve a more careful check of the pipeline system. For example, pipeline companies make pressure tests on the pipeline before the system is brought into service. (For complete specifications on many U.S. inspection practices, see American Petroleum Institute [API] Publication RP1111, Recommended Practice for Design, Construction, Operation, and Maintenance of Offshore Hydrocarbon Pipelines - March 1976, and R. Frank Busby Associates, Underwater Inspection/Testing/Monitoring of Offshore Structures - February 1978.)

Pipeline installations in the North Sea, particularly in the United Kingdom and Norway, have more specific inspection requirements. For example, the Norwegian Petroleum Directorate specifies three types of inspections: initial inspection, start-up inspection and annual inspection. (Norwegian Petroleum Directorate, Guidelines for the Inspection of Primary and Secondary Structures of Production and Shipment Installations and Underwater Pipeline Systems, 1978a, p.13-14). In addition, Det Norske Veritas (Rules for the Design, Construction and Inspection of Submarine Pipelines and Pipeline Risers, 1976) recommends that special inspections be undertaken if the need arises (e.g., in cases of known or suspected damage).

Initial Inspection: After installation, a pipeline system is first visually inspected to determine the success of the pipelaying procedures. Problems such as underwater spans and mechanical damage (e.g., damage to concrete coating) can be detected and documented by videotape or photographs. Other aspects of the inspections may include measurements of:

- burial depths at specific intervals along the pipeline;
- bottom currents; and
- the interior of the pipeline to detect changes in diameter. This is accomplished with mechanical measuring devices (such as "calibrating pigs") which are passed through the pipeline.

Start-up Inspection: Just prior to beginning operation, a start-up safety inspection is made to determine the overall status of the pipeline system. Highly accurate determinations are made of the location and condition of the pipeline in respect to the seafloor. Any problems, such as spanning, are documented using videotapes or other acceptable recording methods. Another internal inspection of the pipeline is also performed.

Annual Inspection: The elements of annual inspection vary from one pipeline system to another and generally depend on the results and experiences of previous inspections. Also given consideration are the operating conditions for the particular pipeline system. The results of each inspection help determine the status of the system and the likelihood of its safe operation until the next annual inspection. Again, the basic elements of the inspection are similar to those of the initial inspection.

Special Inspections: Special inspections are generally required when events occur which might impair the safety, strength or stability of the pipeline including:

- known or suspected pipeline damage;
- signs of pipeline deterioration;
- alteration, repair or replacement of the pipeline or sections of it; and
- where inspections (initial, start-up, or annual) reveal substantial changes in pipeline location, cover or "lying comfort."

Any special inspection would be specifically designed to provide the information necessary to ascertain the location and extent of the problem.

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APPENDIX A

CALCULATING THE AMOUNT OF BOTTOM SEDIMENTS DISTURBED BY SELECTED OFFSHORE ACTIVITIES

This appendix presents the assumptions and calculations made to generate the estimates of bottom sediments disturbed by selected offshore activities as presented in Table 1 of the report.

The first column ("Amount of Sediment Disturbed") contains estimates derived from two sources. Surf clam and sea scallop values are based on similar calculations presented in a report entitled, "A Comparison of Environmental Aspects between OCS Petroleum Activities and Other Selected Activities" by Dana W. Larson (1978), Exxon Company, USA. Otter board trawling calculations are based on personal communications with R.R. Hickman of Exxon Company, USA.

The second column ("Miles of Pipeline") values are calculated based on information from OCS Lease Sale 42's Environmental Impact Statement and from two trench profiles diagrammed in Shell Expro's 1977 report, "FLAGS Gasline Seabed Safety and Stability."

Assumptions and calculations for both columns are as follows:

AMOUNTS OF SEDIMENT DISTURBED BY OFFSHORE ACTIVITIES

I. Surf Clamming

Assumptions:

1. An average boat dredges 8 hours per day/100 days per year.
2. Working speed of a boat is 3 knots.
3. Area of the bottom disturbed is 6 ft wide by 1.5 ft deep. (This equals 2,027 cu yd of bottom sediment disturbed per nautical mile.)
4. One Hundred (100) boats are assumed.

Calculations:

1. For 1 boat:

$$\frac{3\ \text{nautical miles}}{\text{hour}} \times \frac{8\ \text{hours}}{\text{day}} \times \frac{2{,}207\ \text{cu yd}}{\text{nautical mile}} = 48{,}648\ \frac{\text{cu yd}}{\text{day}}$$

of bottom sediment disturbed

2. For 100 boats working 100 days per year:

$$\frac{48.6 \times 10^{3}\ \text{cu yd}}{\text{day}} \times \frac{100\ \text{boats}}{\text{day}} \times \frac{100\ \text{days}}{\text{year}} = 486 \times 10^{6}\ \frac{\text{cu yd}}{\text{year}}$$

of bottom sediment disturbed

II. Sea Scalloping

Assumptions:

1. An average boat dredges 8 hours per day/100 days per yr.
2. Working speed of a boat is 3.5 knots.
3. Area of bottom disturbed is 10 ft wide by 0.25 ft deep. (This equals 563 cu yd of bottom sediment disturbed per nautical mile.)
4. One Hundred (100) boats are assumed.

Calculations:

1. For 1 boat:

$$\frac{3.5\ \text{nautical miles}}{\text{hour}} \times \frac{8\ \text{hours}}{\text{day}} \times \frac{563\ \text{cu yd}}{\text{nautical mile}} = 15{,}764\ \frac{\text{cu yd}}{\text{day}}$$

of bottom sediment disturbed

2. For 100 boats working 100 days per year:

$$15.764 \times 10^{3}\ \frac{\text{cu yd}}{\text{day}} \times \frac{100\ \text{boats}}{\text{day}} \times \frac{100\ \text{days}}{\text{year}} = 158. \times 10^{6}\ \frac{\text{cu yd}}{\text{year}}$$

of bottom sediment disturbed

III. Otter Board Trawling

Assumptions:

1. An average boat trawls 6 hours per day/100 days per year.
2. Working speed of a boat is 3 knots.
3. Each boat pulls one trawl with two 10 foot trawl doors.
4. Area of bottom disturbed is 17 ft wide by 0.25 ft deep. (This equals 957 cu yd of bottom sediment disturbed per nautical mile.)
5. One Hundred (100) boats are assumed.

Calculations:

1. For 1 boat:

$$\frac{3 \text{ nautical miles}}{\text{hour}} \times \frac{6 \text{ hours}}{\text{day}} \times \frac{957 \text{ cu yd}}{\text{nautical mile}} = \frac{17{,}226 \text{ cu yd}}{\text{day}}$$

of bottom sediment disturbed

2. For 100 boats working 100 days per year:

$$17. \times 10^{3} \frac{\text{cu yd}}{\text{day}} \times 100 \frac{\text{boats}}{\text{day}} \times 100 \frac{\text{days}}{\text{year}} = 170 \times 10^{6} \frac{\text{cu yd}}{\text{year}}$$

of bottom sediment disturbed

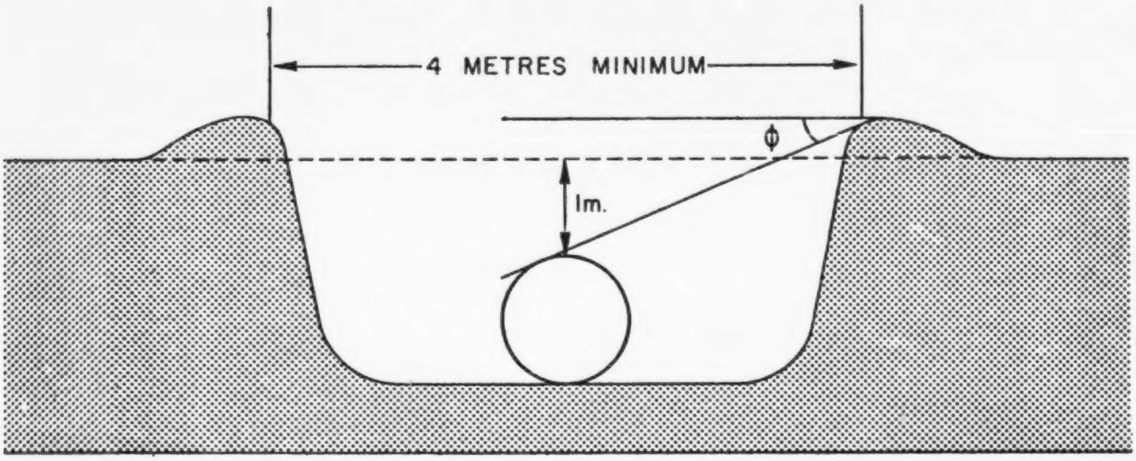
AMOUNTS OF SEDIMENT DISTURBED BY PIPELINE TRENCHING

I. Bureau of Land Management 1977 Estimates - from Environmental Impact Statement - OCS Sale Number 42.

"...if a trench is 5 feet deep and 6 to 12 feet wide, and if a parabolic cross section is assumed, the pipeline would disturb approximately 4000 to 8000 cubic yards of sediment per mile, some of which would be resuspended (p.664)."

II. From: Shell U.K. Expro. 1977. FLAGS Gasline Seabed Safety and Stability - Figure 7, "FLAGS Gasline Typical Trench Profiles," (p.2.).

a. Narrow Trench in Firm Soil (e.g., clay)



Assumptions:

1. Trench is rectangular.
2. Pipeline is 36 inches in diameter.

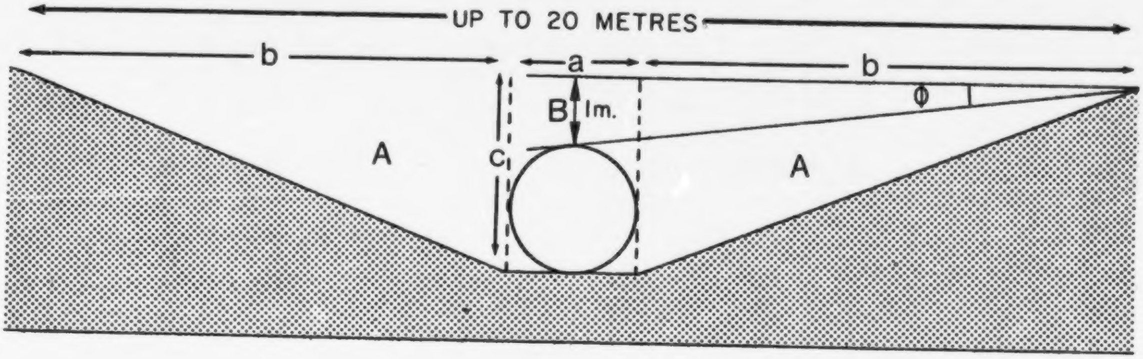
Calculations:

1. Trench depth:

   3 ft pipeline + 3.3 ft (1 meter (m)) above pipeline = 6.3 ft deep
2. Trench width = 13.2 ft (4 m)
3. Amount of sediment disturbed per mile of trenching

$$\frac{6.3 \text{ ft} \times 13.2 \text{ ft} \times 5{,}280 \text{ ft/mile}}{27 \text{ cu ft/cu yd}} = 16{,}262 \frac{\text{cu yd}}{\text{mile}}$$

b. Wide Trench in Soft Soil (e.g., sand)



Assumptions:

1. Assume area of trench is sum of areas of 2 identical right triangles (A) plus rectangle B
2. Pipeline is 36 inches in diameter.

Calculations:

1. To calculate areas:

   a = 3 ft (diameter of pipeline)

   $b = \frac{66\text{ ft }(20\text{m}) - 3\text{ ft}}{2} = 31.5\text{ ft}$

   c = 3 ft pipeline + 3.3 ft (1m) above pipeline = 6.3 ft

2. area of 2 right triangles =

   31.5 ft x 6.3 ft = 198.45 sq ft

3. area of middle rectangle

   6.3 ft x 3 ft = 18.9 ft

4. total area of trench =

   198.45 sq ft + 18.9 sq ft = 217.35 sq ft

5. Amount of sediment disturbed per mile of pipeline trenched

   $$\frac{217.35\text{ sq ft} \times 5{,}280\text{ ft/mile}}{27\text{ cu ft/cu yd}} = 42{,}504\ \frac{\text{cu yd}}{\text{mile}}$$

III. Miles of Pipeline Laid

Each of these three quantities of sediment disturbed per mile was then divided into estimated quantities of sediment disturbed by offshore activities (Table 1, Column 1) to derive three relative values "miles of pipeline laid." These values are presented in Column 2 of the Table.

For example:

$$\frac{1.58 \times 10^8 \text{ cu yd of sediment} \quad \text{disturbed by sea scalloping (Table 1, Column 1)}}{\frac{8000 \text{ cu yd sediment disturbed}}{\text{mile of pipeline trenched (EIS 42)}}}$$

$$\cong 2000 \text{ miles of pipeline}$$

APPENDIX B

INDUSTRY'S PROCEDURES FOR OCS PIPELINE ROUTE SELECTION

by

Pipeline Industry Advisory Task Force
George G. Hughes, Jr., Chairman

SELECTING A ROUTE

Before proceeding with a discussion of the selection of OCS pipeline routes, it is appropriate to briefly describe the general development process and timing for offshore fields. The typical offshore field goes through several developmental stages before any hydrocarbons can be produced. Industry first makes exploratory geophysical studies in the area designated by the Bureau of Land Management (BLM) for the proposed sale to determine which tracts contain geologic structures that might be conducive to hydrocarbon accumulation. One part of the tract evaluation process is the estimation of the transportation costs from the area of the lease sale. Due to the highly proprietary nature of the data associated with each tract, the transportation cost study is usually based on the assumption that production will originate in the approximate center of the proposed lease sale. Because most lease sales include tracts that are geographically separated by 50 or more miles, pipeline routes are selected on a very general basis only. By necessity, this initial study is very general in nature due to the lack of specific data such as hydrocarbon type, production rate, location of the production facilities, etc., and consequently the calculated transportation costs are strictly "order of magnitude" numbers.

Based on the results of the geophysical studies, Industry nominates tracts in the general area of interest and the BLM decides which of the nominated tracts will be offered for lease and begins to prepare an Environmental Impact Statement. After completion of the Environmental Impact Statement and Public Hearings concerning the impact of the proposed sale, the lease sale is held.

At the lease sale, various companies or individuals competitively bid on individual tracts, utilizing a sealed bid process. Once a tract is successfully leased, the leaseholder begins exploratory drilling using a mobile offshore drilling rig to test for the existence of hydrocarbons. These mobile rigs may be the floating variety, such as ship-shaped and semisubmersible vessels or they may be of the bottom-founded variety, such as the jack-up or submersible barges often used in shallow waters.

Exploratory drilling is a two-phase process. In the first phase, a geologic structure is drilled to confirm or deny the existence of a hydrocarbon accumulation. In the second phase, if promising discoveries are made, further drilling is done to establish the extent of the field and to determine whether the field can be developed commercially.

Initial planning for pipelines is done by selecting some very generalized routes for a pipeline to serve the lease area. Based on the best information available (although admittedly speculative), a hypothetical platform is selected and a pipeline route is chosen from the platform to what would seem to be the most likely onshore destination of the hydrocarbons. At this stage, planning does not usually include any "on-site" surveys in the field, but is done using offshore naviagation charts, city, county, and state maps, National Oceanic and Atmospheric Administration (NOAA) quadrangles, OCS official protraction diagrams (where available), and data that are available from the exploratory geophysical studies. The maps consulted are of various scales and are used primarily to identify topographic details that would assist or hinder in the general location of the pipeline. In addition, the mapping is used to determine line lengths and other physical details to aid in further technical and economic evaluation.

To minimize exposure to offshore hazards, the route is usually selected to follow a fairly direct path from origin to destination, to the extent that this is permitted by the natural topography and shore approach. The minimum offshore line length is desirable because of high maintenance costs and required investment.

Offshore pipeline corridors, by reducing the areal extent of the pipeline network, reduce the potential for future finds to be transferred via a portion of an existing system. Corridors are also not considered desirable from either a construction or an operation standpoint. The congestion created by multiple parallel pipelines promotes problems, even onshore, and the anchoring requirements of offshore equipment (see Figure B-1) both during construction and maintenance operations present a recurring hazard to existing pipelines. Several well-planned lines to shore which may be many miles apart, instead of a single corridor or line, offer a major advantage for transporting discoveries made at some later date, by offering trunk lines to

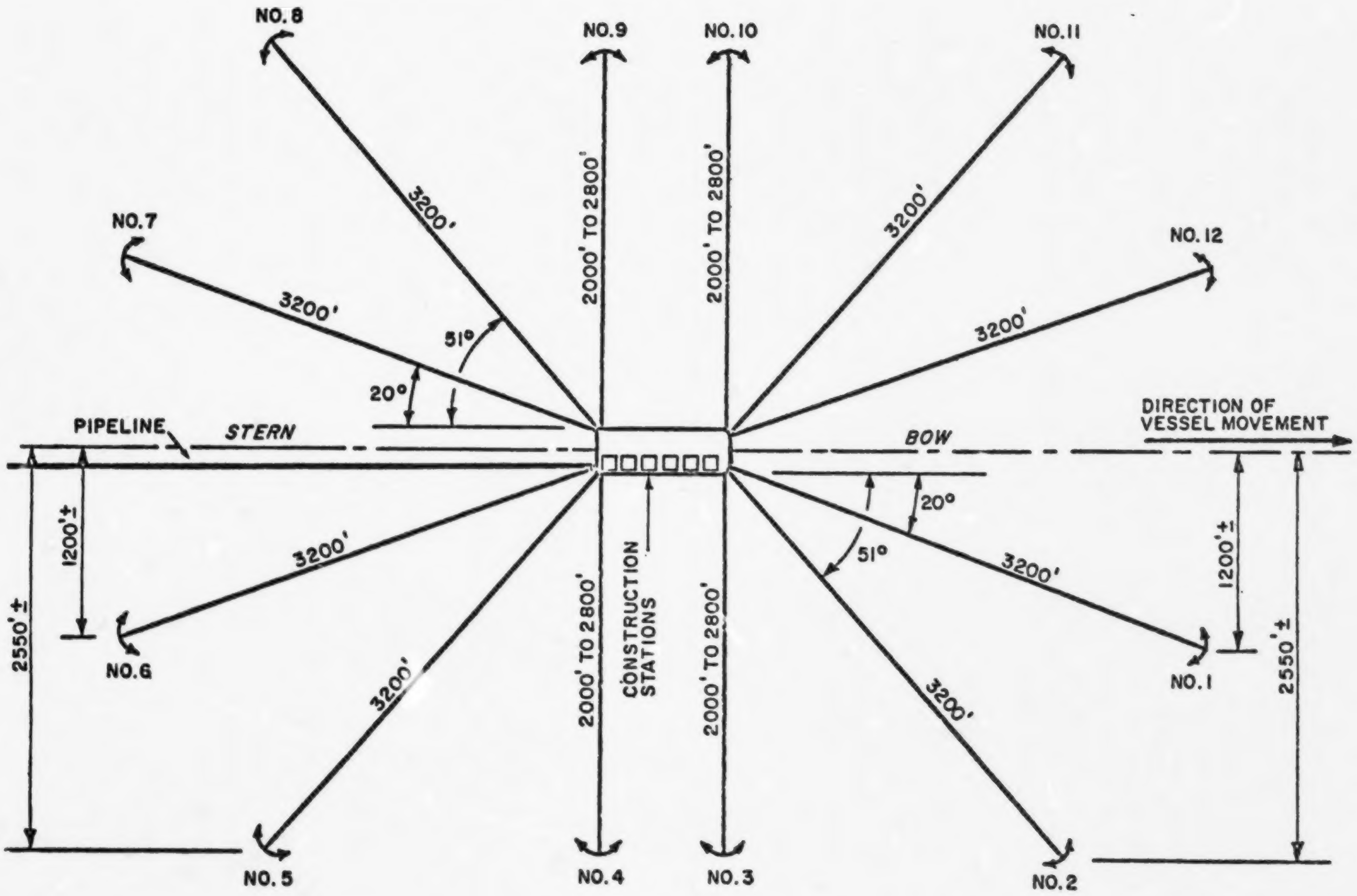

NO. 8
NO. 9
NO. 10
NO. 11
NO. 7
NO. 12
3200'
2000' TO 2800'
51°
20°
PIPELINE
STERN
BOW
DIRECTION OF VESSEL MOVEMENT
1200'±
2550'±
CONSTRUCTION STATIONS
NO. 6
NO. 1
NO. 5
NO. 4
NO. 3
NO. 2

FIGURE B-1. TYPICAL INITIAL ANCHOR PATTERN FOR A 120X420 FOOT LAY BARGE IN 35 TO 100 FEET OF WATER shore in closer proximity to the new discovery. It is not possible to predict where the new discoveries will be when the initial line is laid, as proven by experience in the Gulf of Mexico. Discoveries currently made in the Gulf of Mexico can often be transported via trunk lines laid many years ago, and the fact that there are a number of lines to shore spaced throughout the Gulf offers an opportunity to lay shorter lateral connections than if there were only one or two trunk lines to shore. There have been many discoveries in the Gulf of Mexico that were not large enough to justify the cost of a long lateral line, but which could be developed because of their proximity to an existing trunk line.

Other considerations in the route search include:

- A friendly landfall--(that is, one which is compatible with pipeline construction and maintenance and with the restoration and maintenance of the shoreline; and one which minimizes onshore pipeline impact areas.) Some problem areas evaluated and avoided to the extent possible are congested coastal areas, wildlife preserves, wilderness areas and other known sensitive areas;
- Bottom conditions--Canyons, boulder areas, rock outcroppings, ordinance dumps, unstable areas (such as mud slide, sand wave, and faulting areas) and other identified obstacles are also avoided to the extent possible;
- Ability to eliminate outside forces on the pipeline. Burial of pipelines in shallow water is usually necessary to meet permit requirements and helps to minimize damage from external forces. Ship anchorages and other areas with a high potential for damage to a pipeline are avoided; and
- Ability to minimize effects of the pipeline on the environment. Environmentally sensitive areas such as oyster beds are considered.

Once exploratory drilling confirms the existence of hydrocarbons in commercial quantities, platform and production facility construction in onshore fabrication yards begins. After platforms are constructed, they are transported to the desired offshore location, erected, and attached to the ocean floor with steel pilings. After these stages are complete, development drilling begins. The total time required from the confirmation by exploratory drilling of a commerical field to the initiation of production usually ranges from two to three years. Of course, these timing figures are extremely sensitive to the economic, business, governmental and social climates prevalent at the time of development. For example, material shortages and regulatory and legal delays can drastically increase the time required to develop an offshore area.

After the confirmation of a commercial discovery, one of the critical activities associated with field development is the design and construction of a pipeline system on a timely basis. Once exploratory drilling confirms that the field can be developed commercially, the preliminary routes delineated for transporting the oil and gas are evaluated in detail, considering all engineering and construction factors as well as minimizing all potential environmental disturbances. At this time, suitable high resolution topographic and geophysical route surveys are made to aid in the selection of the final route and for permit application. All of the route selection factors described above in the initial planning stage are now reconsidered based on "on-site" surveys (described in detail below) and a re-evaluation of all available data.

The final planning of the optimum transportation system will also include a survey of other companies who may be involved in developing fields in the discovery area, to obtain production estimates for their fields. From this information, a forecast of overall discovery area production over time--a throughput profile--can be developed and estimates made of the pipeline capacity necessary to support the entire development area. Common pipeline facilities are desirable when feasible, because lower-cost transportation can usually be provided if all producers in an area use common lines (which take advantage of economies of scale).

This throughput profile also determines the pipeline's optimal economic size, an important parameter because of the high cost of offshore construction. Once operational, a line that is too large will require a higher revenue to earn a reasonable return on the investment; a line that is too small will require prorating the available capacity or investing more money to install new pipeline facilities. Every effort, is made, therefore, to optimize the line size. This evaluation is also tempered with consideration of future unforeseen needs.

As it normally requires about a year to obtain large quantities of steel line pipe, it is important that pipeline routes and pipe sizes be established as early as possible in the design process so that line pipe and other critical materials can be ordered.

Once a route is selected, design criteria are developed as a basis for the design of the pipeline. Along with the information gained from the surveys, these criteria are used to prepare an application for a permit for construction. These design parameters are further expanded into a full set of Design and Construction Specifications which satisfy applicable regulatory authorities. These specifications are also used to secure contract bids for construction and are ultimately used by inspectors during the construction of the pipeline.

During the course of the construction, additional engineering, surveying and inspecting are required to see that the pipeline is constructed in the manner and location specified. After construction is completed, an "As-Built" Survey is made to document the actual location of the finished pipeline. "As-Built" Survey results are mapped on a scale of 1" = 4,000' to conform to the Official Protraction Diagram.

SURVEYING A ROUTE

When the need to construct a pipeline has been established, suitable route surveys are made to determine the possible existence of hazards and archaeological remains and to aid in the selection of the final route and the preparation of permit applications. These surveys are usually planned on OCS Official Protraction Diagrams with a scale of 1" = 4,000' and are planned to meet the BLM's requirements for a geophysical hazard survey and an archaeological survey. Surveys performed are:

- Route Survey--Centerline and one offset line each side. Offset lines for use in minor reroutes during construction are generally about 1,000 feet distant from centerline. Location accuracy ranges from about 6.6 feet (2 meters) to 49.5 feet (15 meters). General survey techniques employed are Range/Range, Parabolic and Satellite Navigation.
- Bottom Profile--Usually conducted with a fathometer or other similar type instrument on the center line and both offset lines.
- Sub-bottom Profile--Miniseismic record with penetration to about 25 to 50 feet.
- Magnetometer--Determines magnetic anomalies such as pipelines, cables, wrecks, junk, debris, explosives, ammunition, etc. Depending on survey conditions and anomaly size, detection may range from point location to 200 feet laterally.

- Hazard and Archeological Surveys--The information gained from the above surveys is correlated and studied to develop a hazard survey. These data are also examined by an archeologist to ascertain pertinent archeological facts to a water depth of about 200 feet.

The equipment to conduct these surveys can be housed in a boat 75 feet to 85 feet in length so that all surveys are conducted on a specific course simultaneously. However, the wind/wave/sea-state conditions usually dictate the vessel size. In the Gulf of Mexico, this would be generally in the 100-foot long class where in the North Atlantic, a deep-draft vessel of about 200-foot length might be required.